

**THE EFFECTS OF RISK ATTITUDE ON COMPETITIVE
SUCCESS IN THE CONSTRUCTION INDUSTRY**

A Dissertation

by

HYUNG JIN KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2009

Major Subject: Civil Engineering

**THE EFFECTS OF RISK ATTITUDE ON COMPETITIVE
SUCCESS IN THE CONSTRUCTION INDUSTRY**

A Dissertation

by

HYUNG JIN KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Chair of Committee,	Kenneth F. Reinschmidt
Committee Members,	Stuart Anderson
	John Walewski
	David Bessler
Head of Department,	David V. Rosowsky

August 2009

Major Subject: Civil Engineering

ABSTRACT

The Effects of Risk Attitude on Competitive Success in the Construction Industry.

(August 2009)

Hyung Jin Kim,

B.S., Konkuk University; M.S., Texas A&M University

Chair of Advisory Committee: Dr. Kenneth F. Reinschmidt

This dissertation investigates the latent but critical effects of risk attitude on competitive success in construction applying an evolutionary approach. The approach considers contractors as individual entities competing with each other for common job opportunities, and competition as an evolutionary process in the market.

In construction, competitive bidding is the major mechanism of competition. Bidding itself is an important managerial function in a construction organization while it is risky since the actual cost of a job is unknown. Therefore, contractors' risk-taking in competition is an essential element in the construction business.

Individuals may behave differently in competition depending on their own risk attitude which defines what risks can be accepted or not in an organization. Depending on the differences in risk-taking, the result of a competition varies. How contractors compete, that is, how they take risks in competition affects the competition among themselves. Also, contractors' performance is differentiated through competition to

decide successful firms and unsuccessful firms. The current study investigates the effects of risk attitude, which is the latent basis for contractors' different behaviors in competition.

The current investigation is unique in that it combines: 1) an evolutionary approach; 2) behavioral decision-making under uncertainty; 3) multi-level analyses from the individual to the aggregate; and 4) a long-term perspective on firms' success and life-cycles (birth, death, survival, growth, contraction, and market diversification). The developed evolutionary model simulates and analyzes competition among contractors in the competitive bidding environment. A new method is proposed to represent contractors' different risk-taking behaviors depending on their own risk attitude. The analysis accounts for contractors' differences in risk-taking, their performances through competition, and corresponding organizational changes in life-cycles at the individual level, and aggregate patterns evolving at the population level as resultants of competition over long time periods.

The study finds that risk attitude is a latent but dominant competitive characteristic of contractors by identifying the critical effects of risk attitude on competitive success. The results provide new insights on competition and recommendations for contractors' competitive success, which are not available using conventional approaches.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Professor Kenneth F. Reinschmidt for his great advice and support. I cannot imagine my graduate study at Texas A&M University without him. I sincerely express my grateful appreciation and respect to him.

I also would like to extend my thanks to my dissertation committee members, Professor Stuart Anderson, Professor John Walewski, and Professor David Bessler for their guidance and support. Their review and helpful comments improved the quality of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a wonderful journey.

Finally, and most importantly of all, I want to thank my parents for their support and my wife for her patience and love.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
DEDICATION	v
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES	xii
LIST OF TABLES	xvi
 CHAPTER	
I INTRODUCTION	1
1.1 Background	1
1.2 Organizational Risk Attitudes	4
1.3 Risk Attitude and Firm Performance	6
1.4 Hidden Aspects of Risk Attitude	7
1.5 Multiple Perspectives – Through Individual to Aggregate Levels	9
1.6 Study Scope and Objectives	10
1.7 Organization of the Dissertation	11
II COMPETITION STUDIES	14
2.1 Competition Studies in Construction	14
2.1.1 Classification of Bidding Models and Strategic Studies	15
2.1.2 Original Work by Friedman	18
2.1.3 Estimation of the Probability of Winning	21
2.1.4 Multiple Regression Techniques	24
2.1.5 Internal Conditions, Market Conditions, and Competitors	26
2.1.6 Individual Preferences	29
2.1.7 Go/No-go Decision	31
2.1.8 Other Approaches	34
2.1.9 Summary of Previous Models and Approaches	36

CHAPTER	Page
2.2 Missing Concept in Competition Studies in Construction	39
2.3 Competition Studies in Other Areas.....	40
2.3.1 Studies in Biology and Ecology	40
2.3.2 Competition and Mode of Competition	42
2.3.3 Empirical Findings	43
2.3.4 Studies in Economics and Organization Theory	46
2.4 Size Distribution of Firms	49
2.4.1 Approaches Using Long-run Average Cost Curves.....	50
2.4.2 Stochastic Approaches Using Gibrat's Law.....	51
2.4.3 Equilibrium Approaches	52
2.4.4 Evolutionary Approaches.....	53
2.5 Discussion and Lessons from Other Competition Studies	56
2.6 Summary	57
III RISK ATTITUDE AND FIRM PERFORMANCES.....	59
3.1 Organizational Culture and Risk Attitude	59
3.1.1 Organizational Culture	59
3.1.2 Organizational Risk Attitude.....	64
3.2 Strategic Management Studies	66
3.2.1 Risk-return Association.....	66
3.2.2 Diversification.....	69
3.2.3 Limits of Empirical Studies.....	71
3.3 Characteristics of the Construction Industry	72
3.3.1 Fragmentation.....	73
3.3.2 High Entry and Exit Rates.....	74
3.3.3 Derived Demand	75
3.3.4 High Risks to Contractors	76
3.3.5 Low Level of Innovation and Inefficiency in Learning	77
3.3.6 Risk and Competition, the Unchanged Characteristics	78
3.4 Contractors' Business Failure	79
3.5 Summary	82
IV ANALYSES OF CONSTRUCTION INDUSTRY DATA	84
4.1 Size Distribution - ENR US Top 400 Contractors	85
4.1.1 Size Distribution of ENR Contractors.....	85
4.1.2 Normalization of the ENR Data	90
4.1.3 International Revenues vs. Domestic Revenues	97
4.2 Size Distribution - 2002 Economic Census.....	101
4.2.1 Size Distribution of Establishments in Construction	101
4.2.2 Size Distribution of Establishments in Other Industries	106

CHAPTER	Page
4.3 Interpretation of Power Law in the Size Distribution	108
4.4 Organizational Changes in Employment.....	110
4.4.1 Dynamic Data of the SUSB	112
4.4.2 Static Data of the SUSB	115
4.5 Contractors' Market Diversification	116
4.5.1 Measure of Diversification.....	117
4.5.2 Diversification Pattern of Contractors.....	121
4.6 Summary	125
 V METHODOLOGIES AND DEVELOPMENT OF HYPOTHESES.....	 127
5.1 Evolutionary Approach	128
5.1.1 Evolutionary Approach: General	128
5.1.2 Evolutionary Approach in the Current Study.....	130
5.2 Risk Attitude in Uncertain Situations.....	133
5.3 Expected Utility Theory and Utility Functions	136
5.3.1 Expected Utility Theory	136
5.3.2 Utility Functions.....	141
5.4 Value at Risk and Maximum Loss Allowance.....	143
5.4.1 Value at Risk (VaR)	143
5.4.2 Maximum Loss Allowance (MLA).....	146
5.5 Contractors' Go/No-go Decision	147
5.5.1 Go/No-go Decision Using Utility Functions.....	147
5.5.2 Go/No-go Decision Using Value at Risk	152
5.6 Development of Hypotheses	157
5.7 Summary	163
 VI AN EVOLUTIONARY SIMULATION MODEL	 167
6.1 Development of an Evolutionary Model.....	167
6.1.1 Uses of Empirical Findings	168
6.1.2 Population of Contractors in the Model	169
6.2 Description of the Model.....	170
6.2.1 Initial Conditions and Differentiation by Risk Attitude.....	172
6.2.2 Bid Opportunities and Selection of Bidders.....	173
6.2.3 Contractors' Cost Estimates and Go/No-go Decisions	175
6.2.4 Competition and Actual Costs.....	179
6.2.5 Decision Rules for Contractors' Strategic Behaviors	180
6.2.6 Firm Performance.....	186
6.3 Model Parameters.....	187
6.3.1 Cost Estimate and Markup	188
6.3.2 Actual Costs of Job	190

CHAPTER	Page
6.3.3 Overhead Rate	191
6.3.4 Values of Model Parameters	193
6.4 Summary	195
VII MODEL VALIDATION AND TEST OF HYPOTHESES	197
7.1 Model Behaviors vs. Actual Industry Data	198
7.1.1 Size Distribution of Contractors.....	199
7.1.2 Industry Capacity Changes.....	201
7.1.3 Diversification Pattern of Contractors.....	202
7.1.4 Other Model Behaviors	205
7.2 Comparison of the Two Methods.....	209
7.2.1 Value at Risk vs. Utility Function	209
7.2.2 Comparison of the Simulation Results.....	214
7.3 Test of Hypotheses	217
7.3.1 Distributions of Winning Bids and Success Rates	218
7.3.2 Hypothesis 1: Profitability vs. Risk Attitude	220
7.3.3 Hypothesis 2: Survival vs. Risk Attitude	223
7.3.4 Hypothesis 3: Growth vs. Risk Attitude.....	225
7.3.5 Hypothesis 4: Diversification vs. Risk Attitude.....	226
7.3.6 Hypothesis 5: Diversification vs. Survival.....	229
7.4 Sensitivity Analyses	231
7.4.1 Different Assumptions on Risk Attitude.....	232
7.4.2 Different Assumption on Market Diversification	236
7.4.3 Different Prior Distributions for Risk Attitude Assignment	237
7.4.4 Different Initial Sizes of Contractors	239
7.5 Summary	241
VIII CONCLUSIONS AND RECOMMENDATIONS	243
8.1 Conclusions	243
8.2 Recommendations for Construction Contractors	247
8.3 Contributions.....	250
8.3.1 Investigation on Missing Linkage between Risk-taking and Competition.....	250
8.3.2 New Method to Represent Construction Contractors' Risk Attitude and Behaviors	251
8.3.3 Empirical Findings for the Construction Industry.....	251
8.3.4 Evolutionary Approach for Comprehensive and Multiple Perspectives.....	252
8.3.5 Long-term Analysis on Success of Firms	252
8.4 Discussion	253

	Page
8.5 Study Limits and Proposal of Future Studies	254
REFERENCES	257
APPENDIX I	268
APPENDIX II	270
APPENDIX III	276
VITA.....	281

LIST OF FIGURES

FIGURE	Page
1.1 Hidden Aspects of Risk Attitude.....	8
2.1 Expected Profit and Optimum Value for x	20
2.2 Power Law in Mammalian Population (Marquet et al., 2005).....	45
4.1 Size Distribution of ENR U.S. Top 400 Contractors	88
4.2 Size Distribution of ENR Contractors w/o the Largest Firms	89
4.3 ENR Revenues vs. US Total Revenues.....	91
4.4 Increases in Gross Revenues on the ENR List.....	92
4.5 Size Distribution of the ENR Contractors Using Varying Intervals	93
4.6 Control Chart for Slopes	95
4.7 Control Chart for Intercepts	95
4.8 Size Distribution Using the Mean Intervals	96
4.9 Size Distribution of ENR Domestic Firms Using Varying Intervals	99
4.10 Size Distribution of ENR Domestic Firms Using Mean Intervals	100
4.11 Size Distribution of Establishments in Construction	103
4.12 Size Distribution of Large Establishments in Construction	105
4.13 Size Distribution in the Manufacturing Industry.....	107
4.14 Size Distribution in the Paper Manufacturing Industry	107
4.15 Elasticity by the Power Law.....	109

FIGURE	Page
4.16 Diversity Index for a Firm Operating in Two Sectors	121
4.17 Distribution of the ENR Contractors' Diversity Index	122
4.18 Distribution of the ENR Firms Diversity Index (Domestic)	123
4.19 Distribution of Firms by the Number of Sectors per Firm	124
5.1 Utility Function – Risk-neutral	138
5.2 Utility Function – Risk-averse	139
5.3 Example of Exponential Utility Functions (Risk-averse Case)	143
5.4 Probability Distribution of Possible Outcomes	144
5.5 Example of Normalized Exponential Functions	150
5.6 Alpha & VaR for Unit Normal Distribution	154
5.7 Representation of Go/No-go Decision Making	157
6.1 Flow Chart of the Evolutionary Model	171
6.2 Composition of Firms in the Industry Based on Their Relative Sizes	175
6.3 Comparison of Two Contractors' Cost Estimates and VaRs	178
6.4 Flow Chart – Competition	180
7.1 Size Distribution of Firms (Actual vs. Model)	199
7.2 Size Distribution of Firms in the Logarithm (Actual vs. Model)	200
7.3 Distribution of Firms by Diversity Index	202
7.4 Number of Sectors per Firm	204
7.5 Age Distribution of Firms	206
7.6 Distribution of Firms by the Number of Sectors, Classified by DI	208

FIGURE	Page
7.7 Normalized Utility Functions after the Parameter Adjustment.....	211
7.8 Budget Threshold Using Value at Risk.....	213
7.9 Budget Threshold Using the Assumed Utility Functions.....	213
7.10 Comparison of Two Distributions of Firms, VaR vs. Expected Utility	215
7.11 Distribution of Gross Revenue	216
7.12 Distribution of Firm Diversity Index - VaR.....	216
7.13 Number of Sectors per Firm – VaR vs. Utility Functions.....	217
7.14 Distribution of Winning Bids.....	219
7.15 Distribution of Firms by Success Rate, Classified by MLA	220
7.16 Distribution of Firm Annual Profits	222
7.17 Distribution of Firm Cash Reserves by the Degree of Risk-aversion	223
7.18 Distribution of the 400 Model Firms’ MLA	224
7.19 Distribution of the 400 Model Firms’ Gross Revenues	226
7.20 Distribution of Firm Maximum Loss Allowance for Various DIs.....	227
7.21 Number of Sectors per Firm by Aversion Group.....	228
7.22 Age Distribution of Firms by Diversity Index	230
7.23 Age Distributions of Firms by Capacity	231
7.24 Size Distributions – No Risk-aversion.....	233
7.25 Diversification Pattern – No Risk-aversion	233
7.26 Size Distributions – All Risk-neutral	235
7.27 Diversification Pattern – All Risk-neutral.....	236

FIGURE	Page
7.28 Size Distributions – No Market Diversification.....	237
7.29 Distribution of Firms’ MLA – Triangular Prior I	238
7.30 Distribution of Firms’ MLA – Triangular Prior II	239
7.31 Industry Ratio: Total Revenues / Total Capacity	241

LIST OF TABLES

TABLE	Page
2.1 Major Assessments in Bid Decision (from Mochtar and Arditi (2001)).....	32
2.2 Factors in Bidding Strategy (from Boughton (1987)).....	33
2.3 Summary of Previous Studies - I.....	37
2.4 Summary of Previous Studies – II.....	38
2.5 Main Features in the Evolutionary Model by Dosi et al. (1995).....	53
2.6 Main Features in the Evolutionary Model by Kwaśnicki (1998).....	55
3.1 Work from Competitive Bidding	79
4.1 Slopes and Values of R-squared of the Linear Trend Lines	94
4.2 Analysis on International Revenues by the ENR Contractors	98
4.3 Comparison of 14 years Average Trend lines	100
4.4 2002 NAICS Classification for the Construction Industry	102
4.5 Comparison of Size Distributions for Different Market Sectors.....	105
4.6 Employment Changes in the Construction Industry	113
4.7 Employment Changes in the U.S. Total Industry.....	114
4.8 Average Number of Establishments per Firm.....	116
4.9 Example of Calculation of Diversity Index – Two Sectors A & B.....	120
5.1 Risk-aversion Coefficient and Characteristic of Utility Functions	149
5.2 Relative Classification of Different Risk Attitudes.....	160

TABLE	Page
6.1 Coverage of Markup.....	188
6.2 Estimation of General Overhead	189
6.3 Selling, General and Administrative Expenses (% of Total Revenues).....	191
6.4 Overhead Expenditures (\$Millions) per Employee.....	193
6.5 Model Parameters for Firms and Competitive Bidding in the Market.....	194
6.6 Model Parameters for Contractors' Strategic Behaviors.....	195
7.1 Industry Capacity Changes.....	201
7.2 Classification of Model Firms by MLA	218

CHAPTER I

INTRODUCTION

1.1 Background

Risk is one of the most frequently used terms to describe the characteristics of the construction business. Contractors deal with uncertainties inherent in construction projects that frequently result in unfavorable effects, e.g., cost overruns and schedule delays. Also, the construction business is a project-based or contract-based business. By contract, a contractor takes responsibility for delivering a project on schedule and on budget with specified quality for a contract price, without knowing the actual cost. The inherent uncertainties in the construction business and contractors' diverse approaches to risk management have been key issues in the field of construction engineering and management studies.

In addition to the uncertainties inherent in projects and contractors' risk management at the project level to deal with cost and schedule overruns, contractors face competition in the market place. Contractors compete with each other to obtain jobs available in the market. In many cases of competition, the winner is decided through competitive bidding in which bidders come to a critical decision on whether to bid or not

This dissertation follows the style of the *Journal of Construction Engineering and Management*.

and/or how much to bid. Competitive bidding is the major mechanism of competition in the construction business. It has been favored in both the private (by clients) sector and the public sector (by legislation on competitive procurement).

In the literature, a go/no-go decision on whether to bid or not is described as a complex decision by a contractor since it usually involves multiple decision factors such as current workload, backlog, risks, difficulty of the job, market conditions, relationship with clients, etc. (Boughton (1987); Ahmad (1990); Chua and Li (2000); Lin and Chen (2004)). By making a go decision, if a contractor wins a job, the contractor takes responsibility for the project given a contract price which is the contractor's bid. At the time of bidding, it is unknown whether the job won would be profitable or not. On the other hand, by making a no-go decision, a contractor chooses to wait for new jobs while foregoing the current opportunity. The contractor would not be sure about whether the missed job would be profitable or not, as well as whether a future job would be a better one or not, resulting in an opportunity cost if the contractor accepts a current job.

The decision on bid amount (how much to bid) has been studied in many competitive bidding models since Friedman (1956). The decision is one of the most important managerial functions by contractors since "much of the profit or loss from a project depends upon the bid itself," as de Neufville et al. (1977) asserted. Lowering the bid amount enhances winning probability while it reduces the profitability of a job. In contrast, a higher bid amount decreases the winning probability while it increases the profitability of the job if the job is won. As a result, most competitive bidding models

discuss trade-offs in different combinations of the winning probability and the profitability.

Both the go/no-go decisions and the bid amount or markup decisions are essentially risk-taking by contractors under competition since the contractors do not know the actual costs when they make their decisions for a job. In this risk-taking, some contractors would take relatively more or less risk than others. How contractors take risks could be considered as an identifier to describe the way they do business.

Competition causes additional uncertainties to competing contractors since the contractors do not know exactly who their competitors are (they may encounter new competitors) and how the competitors will bid. The result of competitive bidding always depends on the participating bidders, especially their risk-taking behaviors: how much risk the individual bidders are willing to take in the competition to obtain a job. Alternates to competitive bidding include negotiated price contracts, which eliminate risk due to competition among contractors but retain the risks of cost overrun, and cost-plus contracts, that put the cost risks on the owner. Even using different contract methods, the competition between a contractor and an owner and the competition between contractors still exist, although in different forms.

Based on the discussion above, contractors' risk-taking under competition can be considered as an essential element of the construction business. However, there have been few studies about contractors' risk-taking behavior within the domain of competition at the market level. Most previous competition studies have not considered

enough about competitors or have treated risk attitude as a single decision factor to be considered for an individual contractor's bid decision.

The relevant previous studies maintain that an individual contractor may change its bid decision depending on its own risk attitude or preference (Benjamin (1969); de Neufville et al. (1977); Ahmad and Minkarah (1987); Dozzi et al. (1996); Marzouk and Moselhi (2003)). But, in addition, competitors (other contractors) also may have their own risk attitudes and then this heterogeneity in risk attitude among contractors could affect the results of their competition.

Little attention has been paid to this hidden linkage between contractors' risk-taking attitudes and their competition in the market: contractors' different risk-taking behaviors can affect the competition among themselves. The reason for the deficiency in the literature is due to the impossibility of measuring individual contractors' risk attitudes and in finding available data for such analyses.

1.2 Organizational Risk Attitudes

Organizations develop their own cultures. A firm's culture, especially risk culture or attitude, defines its own approach to dealing with uncertainty (Hillson and Murray-Webster, 2005). Corporate culture determines a firm's risk management in its business decisions.

There have been studies about different risk attitudes among organizations as well as among individuals (von Neumann and Morgenstern (1944); Kahneman and

Tversky (1979); Walls and Dyer (1996); Pennings and Smidts (2000, 2003); Hillson and Murray-Webster (2005)). The heterogeneity in risk attitude has been described using expected utility theory and utility functions (von Neumann and Morgenstern, 1944). In the theory, different risk attitudes are classified into three generic types: risk-averse, risk-neutral, and risk-seeking. Individuals having different risk attitudes behave differently to maximize their own utilities, not to maximize expected monetary value as propounded by expected value theory. A detailed discussion on expected utility theory and utility functions is presented in Chapter V.

By expected value theory, individuals are expected to be indifferent between different outcomes if the expected values of the uncertain events are the same. All firms or individuals should make the same decisions under the same circumstances. So, expected value theory does not allow different decisions among individuals under an identical uncertain condition, which however are observed in the real situations.

Regarding risk management, its importance has been emphasized in construction as well as other industries. And, relevant risk management tools and techniques have been developed and used by researchers in academia and by practitioners in industry. An important fact should be emphasized: in general, different individuals may use the same tool differently. Similarly, depending on their risk attitude, individual firms may have different perceptions on an identical risky event, which lead to different evaluations of the risk and corresponding different actions. In competitive bidding for a job, contractors that have different risk attitudes could behave differently in their risk-taking. Also, bidding is influenced by the particular circumstances of different contractors.

Contractors with large backlogs of work will bid differently from contractors with small backlogs, due to the risks of business failures.

1.3 Risk Attitude and Firm Performance

Over time and through competition in the market, contractors compete to obtain jobs and earn profits or losses, and in the mean time contractors are differentiated to be successful or unsuccessful ones. Contractor's different risk-taking behaviors depending on their own risk attitude could affect their competition and further the individual contractors' performance. An interesting question can be raised about the relationships between risk attitude and contractor's performance: "Is there an appropriate level of risk attitude for contractors in favor of survival and long-term success in construction?"

In an extension, an individual firm's life-cycle (its growth/contraction, death/birth, and diversification) also needs to be analyzed since the changes in the firm's life-cycle must have been caused by the firm's varying performance through competition over time. For growing or large firms, market diversification is usually considered as one corporate strategy for growth. Empirical studies in strategic management have tried to identify the relationship between diversification and firm performance. However, these studies provide controversial results: positive relationships vs. no significant relationship, and even negative relationships between diversification and profitability (Chang and Thomas, 1989).

In addition to the controversial results from the empirical studies, there are somewhat divergent views on diversification. Diversification is a departure from a firm's current experience base. Then, it can be a riskier strategic choice than improving its performance in the current market a firm knows best. Meanwhile, in modern portfolio theory, diversification is described as a way to reduce market risk and risk-averse investors are expected or want to be diversified (Rubinstein, 2002). These divergent views lead to questions about the relationship between organizational risk attitude that affects a firm's risk management and diversification. The relationship has been not confirmed in the literature.

1.4 Hidden Aspects of Risk Attitude

Figure 1.1 illustrates the hidden aspects of risk attitude for the construction contractors investigated in the current study. High levels of risk (business failure) and competition (number of firms) characterize the construction business in which risk-taking under competition is an essential element. Competition will differentiate contractors in the market into successful or unsuccessful ones. Growth and success depend on their individual performances though competition in this highly competitive business environment. Meanwhile, diversification is considered as a corporate strategy for growth and risk management where the effects of differences in risk-taking behavior among contractors could be identified. Most importantly, the basis of contractors' risk-

taking behaviors in competition is their own risk attitude, which is a part of their organizational culture.

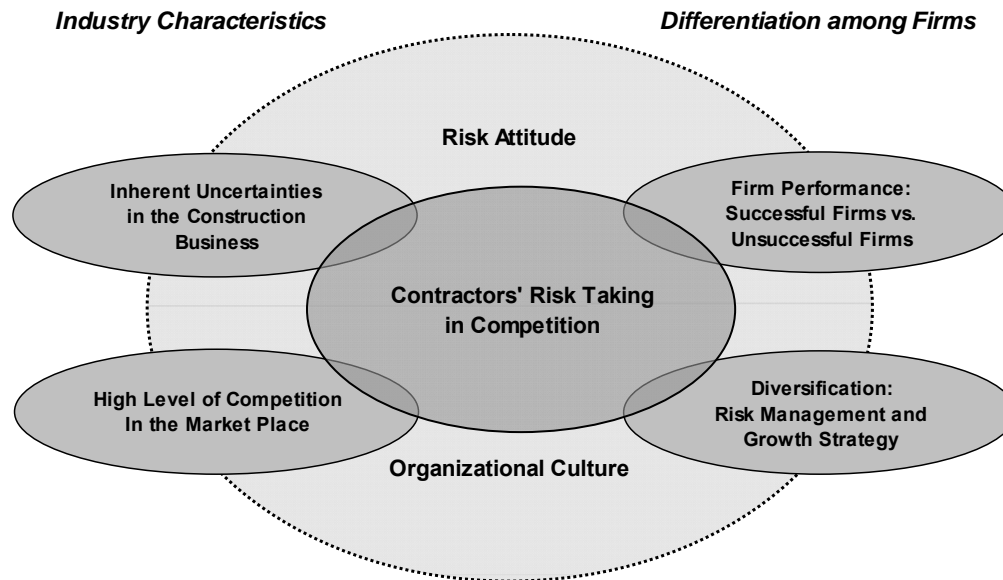


Figure 1.1 Hidden Aspects of Risk Attitude

Analytical studies on organizational risk attitudes and their effects on competition have been limited due to the impossibility of measuring individual firms' risk attitudes and the limited available data for such analyses. However, since risk-taking under competition is essential and universal to any industry member in construction, it is valuable to understand how contractors behave differently depending on their risk attitudes and how their risk-taking affect the competition between all these firms and their performance in the competitive market. The current investigation of the hidden aspects of risk attitude provides specific and useful insights about competition in the construction industry.

1.5 Multiple Perspectives – Through Individual to Aggregate Levels

Selection, in an evolutionary sense, operates through competition among individuals for resources. Competition among individual contractors affects even the population of the individuals. Organizations can affect their own environment as well as their own selection regimes (Erwin and Krakauer, 2004), and how they compete defines the structure of a market (Besanko et al., 1996). Consequently, one can hypothesize that contractors' risk attitude, as the universal trait to define how individual contractors behave in risk-taking under competition, affects the characteristics of the market through the competition among themselves.

Previous competition studies have neglected this point by simply taking account of risk attitude as an individual contractor's decision factor in a bid decision, not as a potentially critical factor universal among contractors. To implement this comprehensive view, the current study takes multiple perspectives to consider the possible causes and effects at different levels from individuals to a population.

At the individual level, contractors have different traits, i.e., their own risk attitudes, which affect their risk-taking behaviors. Through competition among multiple contractors in the market, their performances are differentiated, which leads to different organizational changes in their life-cycles (birth, death, growth, contraction, and market diversification). Over time, some aggregate effects or patterns as resultants of competition, if there are any, could evolve at the population level.

For this comprehensive investigation, an evolutionary approach has been applied. It enables the current study to consider contractors as entities competing with each other

for common job opportunities in a population. In this approach, competition among contractors is expected to drive a selection mechanism in the market. This competition and selection determines the success of a firm over the long-term.

1.6 Study Scope and Objectives

The main research goal is investigating the effects of organizational risk attitude on contractors' competitive success in the construction industry by uncovering whether there is an appropriate level of risk attitude in favor of survival/growth, whether there are relationships between risk attitude and firm performance regarding survival, growth, and diversification, and what effects or patterns evolve at the industry level through the competitive process. As a result, the current study provides recommendations on what contractors can do regarding their survival, growth, and diversification.

The following tasks are performed to achieve the research goal:

- Review relevant competition studies in construction and other areas, and identify what points are missing in previous competition studies in construction and what are applicable to the current study from the relevant studies in other areas for a better analysis;
- Analyze real construction industry data (from Engineering News-Record (ENR) and the U.S. Census Bureau) to identify aggregate patterns that are considered as the resultants of competition, which include the frequency distribution of firm sizes, diversification patterns, and industry capacity changes.

- Propose hypotheses focusing on the effects of risk attitude on competitive success for construction contractors with respect to their economic performance, survival, growth, and diversification;
- Develop an efficient method to represent construction contractors' different risk-taking behaviors in competition depending on their heterogeneous risk attitudes;
- Develop a simulation model based on an evolutionary principle. The model simulates competition among contractors, and tracks the success and failure of construction firms with various genetic risk attitudes over a long period, while monitoring aggregate patterns at the population level that evolves through the competition;
- Validate the simulation results to the actual construction industry data;
- Test the proposed hypotheses using the simulation model; and make recommendations for construction contractors regarding their survival, growth, and diversification.

1.7 Organization of the Dissertation

This dissertation consists of eight chapters. Chapter I discusses the background of the problem and the research objectives. Chapter II provides a literature review of previous competition studies in construction as well as in other areas. In Chapter II, the

current study identifies missing concepts in the previous competition studies and proposes an efficient approach to resolve the missing concepts.

Chapter III provides a literature review of previous studies regarding organizational culture and risk attitude, and analyses of firm performance conducted in the field of strategic management. Also, competition and other characteristics of the construction industry are discussed together with several studies focusing on contractors' business failures. The discussion emphasizes the significance of competition and organizational issues in the construction business.

Chapter IV performs quantitative analyses using the U.S. construction industry data to identify aggregate patterns in the industry, which are resultants of the competition among individual contractors in the market place. The analyses identify the size distribution of construction firms, diversification patterns, and industry capacity changes due to individual contractors' employment changes by their expansions, contractions, deaths, and births.

Chapter V details the research methodology developed for the investigation. Multi-level analyses within the evolutionary approach are discussed. The chapter also introduces a new method developed to represent contractors' different risk-taking behaviors in competition depending on their own attitudes using the newly defined metrics of Maximum Loss Allowance (MLA) and Value at Risk (VaR). Research hypotheses are developed in this chapter.

Chapter VI describes the structure and algorithms used in the evolutionary model developed. The descriptions cover scope and development of the model, application of

the new representation method developed in Chapter V to the model, decision rules for firms' strategic behaviors, and model parameters.

Chapter VII conducts validation of the model and tests the hypotheses developed in Chapter V. Comparisons are made between the simulation results and empirical findings from the actual U.S. construction industry data analyzed in Chapter IV. The results of the hypothesis tests reveal critical effects of risk attitude on competition among contractors and, even further, on aggregate industry patterns. The new method to represent contractors' risk attitude is tested by comparing it to the conventional method using expected utility. Also, sensitivity analyses are performed to confirm the validity of the results of simulation.

Chapter VIII discusses the achievements of research goals, conclusions, and contributions. The chapter provides recommendations for construction contractors regarding competitive success in the construction market. In addition, the chapter proposes potential further studies to investigate other aspects of competition in construction.

CHAPTER II

COMPETITION STUDIES

The current study takes a more comprehensive perspective than previous competitive bidding studies. Beyond making improvements on the previous studies in construction, the current study reviews other approaches used in different competition studies in other research areas and develops its own efficient approach for the investigation. Literature reviews in the current chapter include the following:

- Competition studies in construction and missing concepts;
- Competition studies in other areas;
- Empirical findings from the competition studies in other areas; and
- Size distribution of firms, an aggregate pattern in an economic market.

2.1 Competition Studies in Construction

Competition studies in construction have focused on competitive bidding that is the major mechanism in which contractors compete with each other to obtain jobs in the market. The focus on competitive bidding is due to the characteristics of the construction business described below.

Construction contractors obtain their jobs from the demand available in the market and few jobs are generated by contractors themselves. About 99% of the construction work by contractors is generated from owners in the industry (Rice and Heimbach, 2007). In this project-oriented or contract-based business, every single project is essential input for a firm's business operation. Acquisition of new contracts is a critical managerial function in a construction organization (Willenbrock, 1973).

There have been a significant number of competitive bidding models in the literature, starting from Friedman's model (1956), which is the origin of this field of study. It is a probability model to find the optimum markup to maximize the expected profit from a job. Hence, the model does not include risk attitudes. Since Friedman's model, various enrichments have been built by applying new and different ideas. The following sections review the previous competition studies in construction.

2.1.1 Classification of Bidding Models and Strategic Studies

Due to the variety of methods and approaches proposed in previous studies, there is no agreed classification of the competition studies for construction in the literature.

Different classifications are found as below.

Benjamin (1969) and Griffis (1971) classify the literature on competitive bidding into two major streams:

- Decision theoretic approach; and
- Game theoretic approach.

Models using the decision theoretic approach follow the concepts in Friedman's model. They rely on probability theory while taking the individual perspective for a firm. In many cases, it is assumed that bidders' bids (competitors' behaviors) can be described by probability distributions. Also, it is assumed that competitors' bids are independent, business conditions are static, and all bidders are risk-neutral.

On the other hand, the game theoretic approach takes the market perspective by considering competitors' different actions (Weverbergh, 2002). In construction, there are a very small number of studies taking the market perspective compared to the number of studies taking the individual perspectives.

Boughton (1987) proposes a different classification for the bidding strategies or competitive bidding studies into the three categories:

- Adaptive approach;
- Quantitative approach; and
- Strategic approach.

The adaptive approach considers individual contractors' learning from previous bid experience as an effective factor for contractors' bid decisions. Contractors adapt their bids depending on their recent performance in bids. In this approach, each job is a single business opportunity and contractors try to win more jobs up to the limits of their capacity.

Secondly and differently, the quantitative approach takes decision approaches similar to the concepts of the theoretical competitive bidding models. This approach requires historical data of bids (for a contractor as well as its competitors) to determine

the probability of winning and estimate profitability under static conditions, i.e., bidders behave as they have done and business conditions are static.

Finally, the strategic approach considers contractor's short or long-term strategy. A contractor considers bidding as a continuous process and selects jobs based on the value of the job to the contractor, which is determined based on the contractor's business factors such as business objectives (short/long-term), risk, competitors, the contractor's current workload, etc.

Recently, Marzouk and Moselhi (2003) classified previous competitive bidding models into the following three categories:

- Statistical models;
- Multi-attribute utility theory and analytic hierarchy process type models; and
- Artificial intelligence models.

Statistical models are similar to the decision theoretic approach or the quantitative approach in the previous classifications. Multi-attribute or analytic hierarchy process type models quantitatively evaluate multiple decision factors under consideration for the contractor's bid decision. And, artificial intelligence models are to develop an agent or artificial intelligence that can solve decision problems on behalf of humans. Among these, the utility theory type models consider contractors' risk attitude (Ahmad and Minkarah (1987); Dozzi et al. (1996); and Marzouk and Moselhi (2003)). These models emphasize that individual contractors may have different preferences on their decision factors and a competitive bidding model should represent the differences.

As discussed above, the literature provides different classifications of previous competition studies. The previous approaches have been devised in a divergent way. Nevertheless, as de Neufville et al. (1977), Ahmad (1990), and Mayo (1992) asserted, most competitive bidding models for the construction industry follow Friedman's model with some modifications or extensions.

In addition to the competitive bidding models that aim at finding optimum markups or bid amounts, there is a different type of competition studies on contractors' go/no-go decision in bid. These studies pay more attention to contractors' screening of jobs based on their decision factors such as profitability, the level of risk, current workload, difficulty of job, etc.

The following sections provide descriptions of Friedman's original work and later competitive bidding models, as well as the studies on contractors' go/no-go decisions. Instead of classifying the previous studies by methodology or approach applied, the following discussions are listed by what improvements have been made. After the review of these studies, tabulated summaries are provided in tables on pages 37 and 38.

2.1.2 Original Work by Friedman

Friedman (1956) provided the basic conceptual structure for many of the later competitive bidding models and studies. In this section, Friedman's model is discussed in detail as the original work in this field of study. The major objective of Friedman's

model is to maximize expected profit from a job from an individual contractor's perspective. Friedman's model is described below.

True cost (actual cost) of a job under bid is unknown when the bidders submit their bids. The unknown true cost could be different from a contractor's estimate (c) due to the contractor's own bias, inaccuracy or variability of the cost estimate, or uncertainties inherent in the job. $H(s)ds$ is defined as the probability that the ratio of the true cost to the estimated cost (c) is between S and $S + dS$. When x is the bid amount for the contract, the profit will be $[x - Sc]$ conditional on x being the winning bid. $P(x)$ is defined as the probability that a bid of x will be the lowest and win the contract.

A contractor can predict $P(x)$ by studying previous bidding data for the contractor itself as well as its competitors. Using previous bidding data, a pattern of the contractor's behavior relative to its competitor's cost estimate can be drawn as a distinct probability distribution. Friedman proposes to apply this method for all potential competitors assuming independence between competitors' bids. $P(x)$, if the competitors are known, is simply the product of the probabilities of defeating each of the known competitors under the independence assumption. Friedman considered a situation when a contractor does not know the identity of its competitors and the number of competitors and suggested using the average of the competitors' bid distributions.

The expected profit from a job under bid can be expressed as in Equation 2.1.

$$E(x) = \int_0^{\infty} P(x)[x - Sc]H(S)dS \quad [2.1]$$

Equation 2.1 provides a rational basis for the analysis of competitive bidding: the probability of winning $P(x)$ increases by decreasing the amount of bid x , however the decreased amount of bid x reduces profitability $[x - Sc]$ for the contract, *and vice versa*. Therefore, as described in Figure 2.1, the optimum value for x may exist to find the best combination of the probability of winning $P(x)$ and the profitability $[x - Sc]$, which maximizes the expected profit from a job.

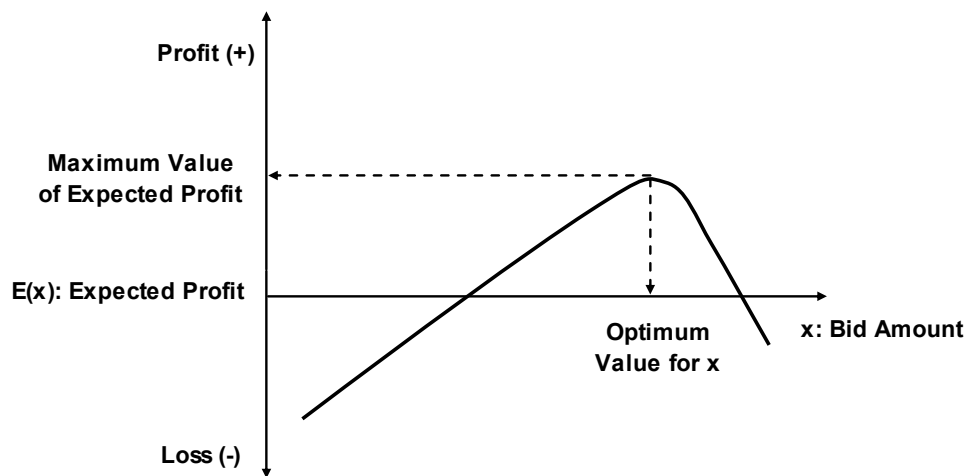


Figure 2.1 Expected Profit and Optimum Value for x

Friedman's model can be criticized due to the assumptions used: it assumes that competitors will continue to bid as they have in the past and the sequence of bids is statistically independent. Therefore, Friedman's model is static. Nevertheless, his model is the origin of this field of studies on competitive bidding and has provided later studies with the conceptual framework.

2.1.3 *Estimation of the Probability of Winning*

The fundamental concept in most competitive bidding models is finding the best combination of the probability of winning and the profitability from a job. As to the estimation of the winning probability, different methods have been proposed and tested in the literature.

Controversies on the Independence Assumptions

There have been controversies on the estimation of winning probability, especially between two methods proposed by Friedman (1956) and Gates (1967) (Fuerst (1976); Weverbergh (2002)). Gates used almost the same conceptual approaches and assumptions, but contrary to Friedman's model, he rejected the independence assumption.

According to Gates (1967), the probability of winning over n equally matched competitors can be defined as $1/(n+1)$. The probability of winning over competitor i is $P(i)$ and the probability of winning over each of competitors is a different value. Then, the probability of winning P against n number of competitors can be estimated as in Equation 2.2.

$$P = \frac{1}{\sum_{i=1}^n \frac{1-P(i)}{P(i)} + 1}$$

Assuming n number of *typical* competitors,

[2.2]

$$P = \frac{1}{n \times \left(\frac{1-P(t)}{P(t)} \right) + 1}$$

On the other hand, Morin and Clough (1969) proposed a modified version of Friedman's method to estimate the winning probability. They developed a computer program, OPBID (Optimum Bid), which was applied to an actual contractor's real business. Three years' actual bid data of a contractor were analyzed. It was the first computer application of competitive bidding model.

They suggested classifying competitors into key competitors and average competitors. The classification is based on the frequency of encountering the competitors in previous bids. Their winning probability is estimated using Equation 2.3. The proposed method also assumes independence among competitors as in Friedman's approach. However, in their analysis, a weighting method was used to give more importance to the recent data, which considers changes in competitive situation in the market.

$$P = \left[\prod_{r=1}^{N_{key}} P(E_r) \right] \times [P(E_{avg})]^{N_{avg}} \quad [2.3]$$

Where N_{key} = the predicted number of key competitors;

$P(E_r)$ = the probability of submitting a lower bid than competitor r , one of key competitors;

$P(E_{avg})$ = the probability of submitting a lower bid than an average competitor;

and

N_{avg} = the predicted number of average competitors.

Empirical Tests

Besides the theoretical development of models, there have been empirical tests of the developed models using actual historical data. Benjamin (1972) tested the validity of competitive bidding models using 3 years' data from a middle-size general building contractor. Especially, he tested the estimation of the probability of winning using the probability distribution of competitors bid ratios, which was proposed by Friedman (1956) and later competitive bidding models.

The contractor in the data participated in bids for 131 jobs over the time period, won 17 jobs, and encountered 189 different competitors. Among them, 97 different competitors bid once and 153 different competitors bid five or fewer times against the contractor. So, there were 36 different competitors that bid more than five times against the contractor. Using the data, Benjamin (1972) constructed bid distributions. However, the distributions showed apparent random variances due to the large number of different

competitors and the variations in their bids. Benjamin questioned the validity of estimation of the probability of winning proposed by competitive bidding models.

On the other hand, de Neufville et al. (1977) analyzed a larger amount of historical bid data from the Massachusetts Department of Public Works. Their data cover 3,262 bids for 691 highway projects from 1966 to 1974. Using the public record, cumulative distribution functions were constructed for different numbers of bidders. They found that the probability of winning a job against n number of competitors can be accurately predicted using the method proposed by Friedman, which is based on the independence assumption.

Compared to the test by Benjamin (1972) that found large variances using a relatively small amount of historical data, the empirical tests by de Neufville et al. (1977) can be considered more reliable since they used a large amount of historical data. However, it indicates that application of the proposed method to real business by individual contractors would not be easy since the method requires a significant amount of historical data.

2.1.4 Multiple Regression Techniques

Instead of using probability distributions of bids by competitors, multiple regression techniques have been proposed for contractor's bid decision. Carr and Sandahl (1978) proposed a multiple regression technique to determine the value of the lowest bid. In their multiple regressions, the dependent variable is the value of the

lowest bid and the independent variables are other various factors that affect the winning probability. The factors are classified into three categories:

- Characteristic of the particular job;
- Economic environment; and
- Level of competition.

They proposed a list of 33 potential independent variables that could have direct/indirect relationships with the lowest bid value. Similarly, Seydel (1994) also proposed use of multiple regression techniques for contractors' bid decisions. These approaches assume that a contractor maintains sufficient data on its own bids as well as its competitors to develop a regression model. The validity of real application of these methods requiring sufficient data is questioned. Benjamin (1972) asserts that it would be very difficult for an individual contractor to attain all relevant bid data to use the competitive bidding models. It would be more difficult for contractors to obtain the relevant data in the private sector where winning and losing bids are usually not made publicly available.

Also, using the regression technique can be criticized due to its static attributes: competition is dynamic in a market and it would be difficult to apply a regression model to the dynamic situation. A regression model explains associations between variables, but not causal relationships (effects and causes) of a change that might occur in a dynamic situation. Also, adding more independent variables increases the size of the data set needed.

2.1.5 Internal Conditions, Market Conditions, and Competitors

The conventional competitive bidding models can be criticized due to static assumptions. Some competitive bidding models consider dynamic factors that can affect contractors' bid decisions over time periods such as individual contractor's internal conditions (e.g., current workload or backlog), changes in the market conditions, competitors' different behaviors, etc.

Contractor's Internal Conditions

Griffis (1971) and Mayo (1992) pointed out that a contractor's markup decisions and its objective may vary over time periods depending on its own business condition. Griffis (1971) introduced a representation of the volume of work versus time for individual contractors with the lower and the upper bounds to describe changes in contractors' desire to obtain jobs over time. The lower bound is set based on the fact that a contractor wants to keep its current volume of work above a certain level to pay its necessary overhead. The upper bound is set by the contractor's bonding capacity or operational capacity constraints. A contractor is expected to behave in such a way as to keep its current and projected workload at some desired level.

Mayo (1992) applied a similar concept to develop a competitor's workload related utility functions. In the proposed model, the contractor bids in order to maximize its own utility function depending on the contractor's current workload.

Market Conditions

The dynamic aspects of competition in construction are also discussed by de Neufville et al. (1977). In their analysis using historical bid data, they found an inverse relationship between the amount of job opportunities and intensity of competition and different bidding patterns depending on economic conditions.

They found that the number of bidders per job tends to increase when the number of jobs decreases in a market. Contractors are usually reluctant to shrink in size even in a market downturn when available jobs in a market decrease (Kim, 2004). Contractors want to maintain their workload in balance with their current operational capacity, which increases the number of bidders per job and reduces markups.

In addition, de Neufville et al. (1977) found that contractors bid lower in bad market conditions to be more competitive. In a bad market condition, reduced job opportunities lead to an increased number of bidders per job as discussed above, and a winner is decided at a higher level of competition with a lower bid. These market dynamics are also discussed by Kim and Reinschmidt (2006).

Changes in Competitors' Behaviors Associated with Market Conditions

Most competitive bidding models use the static assumptions: competitors bid as they did in the past and the market condition is stable. These assumptions ignore the fact that competition would become more severe when the market goes down (de Neufville et al. (1977); Kim (2004)) and competitors would behave differently depending on their own business conditions (Griffis (1971); Mayo (1992)).

The consideration of competitors needs to take a comprehensive market perspective or a game theoretic approach. In game theory, it is assumed that players are rational and intelligent, and their interests are opposed to competitors (Benjamin, 1969). Runeson and Skitmore (1999) pinpoint the differences between the game theoretical approach and conventional decision theory (tendering theory) used in most competitive bidding models as below:

“Game theory requires that all players consider their respective strategies and select the most appropriate strategy assuming that all other players do the same. It does not apply to a situation where one player alone is allowed to adopt a preferred strategy without any attempts from other players to modify their strategies in response. The assumption in tendering theory that there is no response, no modification of the behavior of other players violates the most fundamental assumption of game theory.”

There are a very small number of competition studies in construction using a game theoretic approach (Benjamin (1969); Griffis (1971)). Among these few studies, Kim and Reinschmidt (2006) simulated competition among multiple contractors to represent (re)actions and interactions among contractors in an assumed market by allowing individual contractors to control their markup levels depending on their own conditions based on common decision rules.

In the model by Kim and Reinschmidt (2006), a contractor can enhance its marketing efforts or lower its markup level to obtain more jobs and also can increase its capacity to perform the increased volume of jobs obtained *and vice versa*, depending on market conditions or an individual firm's own short/long-term strategy (i.e., in the

responses to demand change in the market as well as to strategic deviation by competitors). Three important managerial functions (marketing function, markup control, and capacity control) are integrated for individual firms' responses which are made to keep their own balance between workload and capacity. In addition, firms' growth and contraction are represented in the model by the capacity control, which has not been considered in previous competitive bidding models. This study provides a comprehensive market perspective on the competition among contractors and dynamics in a market, and considerations of different long-term and short-term competitive strategies.

2.1.6 Individual Preferences

de Neufville et al. (1977), Shash (1993), and Christodoulou (1998) point out that existing bidding models are not in much use because the models fail in representing how contractors actually behave in the real business situations. Benjamin (1969) and Boughton (1987) also criticize the limits of the competitive bidding models by emphasizing that individual contractors would evaluate differently the worth of varying bid opportunities. To account for these problems, some competitive bidding models have considered the individuality in contractors' preferences.

Benjamin (1969) maintained that contractors' attitudes toward winning and risk vary with their own condition since they evaluate each job differently depending on the condition. He suggested using utility values to represent different risk attitudes of contractors, but applying the same fundamental concept in most competitive bidding

models. Using utility functions, the optimum bid amount is found for a contractor by maximizing the product of expected utility conditional on the probability of winning with given bid amounts.

de Neufville et al. (1977) conducted a questionnaire survey to measure risk-aversion of five contractors. Contractors' risk-aversion was measured assuming different hypothetical conditions with respect to job size (large vs. small) and market conditions (good vs. bad). They found different degrees of risk-aversion of the contractors. Based on the findings, they asserted that current bidding models need to account for contractor's risk attitude.

Ahmad and Minkarah (1987) extended the concept of individual preference and considered that contractors would have different preferences on each of profit, loss, and general overhead. The different preferences are represented using three separate utility functions which are integrated into one expected utility function through normalization for the decision maker's bid decision.

Dozzi et al. (1996) developed a utility theory model considering twenty one decision criteria in the bidding situation. The proposed model allows individual decision maker's different preferences on each of the multiple criteria, which are represented by assigning different weights over the multiple criteria. Similarly, a decision support tool proposed by Marzhouk and Moselhi (2003) uses the multi-attribute utility theory and analytic hierarchy process (AHP).

The above models or studies maintain that bid decisions should be made based on individual contractors' preference or risk attitude and their own condition. However,

most studies do not consider that competition is developed by multiple competitors and each of the competitors also has its own preference, and result of a competition is always relative depending on how individual competitors behave in the competition.

2.1.7 Go/No-go Decision

A contractor would make sequential decisions for a job in a competitive bidding: a go/no-go decision and then a markup decision. Upon that, previous studies can be classified by the decision process on which the study focused: 1) studies about go/no-go decision and 2) studies about decision on markup/bid amount. The studies about contractors' go/no-go decisions discuss more about multiple decision factors for the decision on whether to bid or not. However, it is not easy to clearly differentiate between the markup decision models and the go/no-go decision models since there are models to consider both decision processes.

The importance of go/no-go decision is emphasized in the literature since even a single bad project could significantly damage a contractor's business. However, in practice, bid decisions are based on intuition, gut feelings, experiences, and guesses (Ahmad (1990); Mochtar and Arditi (2001); Rice and Heimbach (2007)). Rice and Heimbach (2007) highlight this problem as "Many contractors do not have a well-defined process for making go/no-go decisions when deciding whether to take on a project. In a highly competitive business, one bad project can mean an unprofitable year, or worse."

Mochtar and Arditi (2001) performed a questionnaire survey for the US top 400 contractors regarding their current pricing practices and found most contractors use their intuition after subjective assessment on competition for their bid decisions. Their finding can be summarized as shown in Table 2.1. The scores are based on contractors' multiple choices.

Boughton (1987) also performed a questionnaire survey to identify what factors are considered important by U.S. general contractors in their bidding strategies. A total of 126 firms responded among the randomly sampled 400 firms. Table 2.2 lists the identified important factors. Each factor shows the weighted mean on a 7-point scale, where 7 is most important and 1 is most unimportant.

Table 2.1 Major Assessments in Bid Decision (from Mochtar and Arditi (2001))

Rank	Type of Assessment	Score (multiple choices)
1	Intuition	50.5%
2	Subjective assessment of the competition	60.4%
3	Empirical models	24.2%
4	Probability/mathematical models	14.3%
5	Risk/value of project	12.1%
6	Current workload	13.2%

In addition, Chua and Li (2000) focused on underlying determining factors rather than the decision itself. They also conducted a questionnaire survey to identify decision factors considered in go/no-go decision and classified them into four categories: competition, risk, need for work, and company's position in bidding (suitability of jobs to company's specialty and resource). Total twenty eight key determining factors were identified. Refer to Chua and Li (2000) for the details.

Table 2.2 Factors in Bidding Strategy (from Boughton (1987))

<i>Rank</i>	<i>Factor</i>	<i>Score</i>
1	<i>Clearness of detail of specifications</i>	5.37
2	<i>Past experience with similar work</i>	5.19
3	<i>Confidence in subcontractor bids</i>	4.97
4	<i>Location of project</i>	4.90
5	<i>Number of competitors</i>	4.87
6	<i>Duration of project</i>	4.57
7	<i>Workload</i>	4.56
8	<i>Market condition</i>	4.54
9	<i>Size of bid</i>	4.51
10	<i>Opportunity for follow-on work</i>	4.32
11	<i>Relationship with architect and owner</i>	4.02
12	<i>Competitors' bid history</i>	3.56
13	<i>Confidence</i>	3.41

As discussed above, a bid decision requires consideration of multiple decision factors and it evolves unclear evaluations such as intuition, subjective assessment of competition, risk, confidence, etc. Due to complexity in the consideration of multiple factors and vagueness in the evaluation of them, how a go/no-go decision is made within a construction organization is not clear (Lin and Chen, 2004). Thus, the main goal of most go/no-go decision studies is providing a rational basis for project evaluation and clarifying the decision procedure by quantifying qualitative issues under consideration.

Lin and Chen (2004) classify different approaches to the bid evaluation into four categories: 1) scoring methods; 2) multi-attribute decision making; 3) the analytic hierarchy process method, and 4) fuzzy set approaches. A common approach proposed in the literature can be described using a study by Ahmad (1990). Ahmad proposed a weight additive model, in which the individual worth of different business factors is weighted based on decision maker's preference and summed additively to obtain an

overall score. To make a go decision in the approach, the overall score should be greater than a desired minimum score that is set by the decision maker.

2.1.8 Other Approaches

This section reviews other approaches in the literature that were not discussed above. Broemser (1968) proposed a sequential bid model to overcome the deficiency of the single bid model which does not consider contractors' bonding capacity and loss of opportunity of future projects. The proposed model aims at maximizing economic welfare of the firm using an integer program. The objective function is to maximize the expected discounted present value of the bids under constraints that are based on bonding capacity and opportunity losses. The proposed model considers a relatively longer time-frame for contractors' business operation.

Chen (1991) suggests that contractors make bid decisions considering projects as a portfolio at the firm level assuming correlations between multiple projects. So, a bid decision should be made to maximize the overall present value of potential portfolio that will consist of the existing portfolio and an additional new project. Han et al. (2004) take a similar approach for international contractors to consider projects as a portfolio at the firm level focusing on financial risks.

Some approaches have been proposed to deal with the characteristics of contractors' bid decision: subjective and qualitative. Christodoulou (1998) developed an artificial intelligence model to decide optimum bid markup. The proposed fuzzy artificial neural networks account for fuzziness in qualitative factors and the complexity

in bid decision problems with multiple factors. Lin and Chen (2004) proposed a fuzzy linguistic approach to quantify and incorporate multiple qualitative factors in decision making process. Similarly, linguistic terms are used to overcome vagueness and subjectiveness in evaluation of each of decision criteria. Relative importance of each of screening criteria and corresponding rates are expressed by decision makers in linguistic terms that are assigned appropriate fuzzy numbers, which are aggregated to decide an attractive rating for a job under consideration.

Most of previous competitive bidding models assume cost-based pricing: a contractor estimates project cost for a job and adds a markup to the estimated cost to decide a bid amount. Mochtar and Arditi (2001) proposed to use a market-based pricing strategy by criticizing that cost-based pricing cannot account for dynamic competition in the market. According to them, the market condition in construction is ever changing, which develops different levels of competition. So, contractors need to pay attention to changes in the market condition rather than relying too much on cost-based approach for their pricing.

Lowering price is a common business strategy by contractors since it is easy. Also, this practice becomes more prevalent among contractors when the market goes down. Chao and Liou (2007) recognized that, from contractors' perspective, survival outweighs making a profit in such a situation. Then, a contractor's objective could be obtaining jobs while minimizing losses. In that, they proposed a probability model that determines the lower limit of the bid by maximizing the expected probability of not making a loss within the project period while considering opportunity loss conditional on losing the job. The approach aims at minimizing a contractor's overall risk of loss.

2.1.9 Summary of Previous Models and Approaches

Previous competition studies in construction have been performed in divergent ways so that it is difficult to classify them. Nevertheless, Tables 2.3 and 2.4 summarize the various studies by their specific ideas and additional considerations that each study proposed.

Table 2.3 Summary of Previous Studies - I

Unique Feature	Studies	Main Ideas and Considerations
Origin	Friedman (1956)	Original probabilistic model assuming contractors' bids are independent over time.
Estimation of Wining Probability	Gates' Model (1967)	Rejected the independence assumption from Friedman's model.
	Morin and Clough (1969)	Developed a computer program of a probabilistic model.
	Benjamin (1972)	Analyzed three years' bid data and tested validity of the winning probability estimation proposed.
	de Neufville et al. (1977)	Analyzed historical bid data to test validity of the winning probability estimation proposed.
	Carr and Sandahl (1978) Seydel (1994)	Proposed multiple regression techniques using actual data to estimate the optimum bid amount assuming sufficient data.
Different Business Conditions	Griffis (1971) Mayo (1992)	Considered contractors' varying objectives depending on contractors' internal conditions such as current workload and market conditions.
Interactions among Contractors	Kim and Reinschmidt (2006)	Developed a game theoretic approach considering interactions among contractors in competitive bidding situation.
Individual Preferences	de Neufville et al. (1977)	Measured contractors' risk-aversion based on their questionnaire survey.
	Benjamin (1969)	Considered differences in project evaluation and attitude among contractors.
Utility theory And Multi-Attribute Utility	Ahmad and Minkarah (1987)	Considered contractors' different preferences on profit, loss, and general overhead using utility functions.
	Dozzi et al. (1996)	Proposed a utility theory model to represent a contractor's individual preferences on multiple decision criteria.
	Marzhouk and Moselhi (2003)	Proposed a decision support tool using the multi-attribute utility theory and AHP.

Table 2.4 Summary of Previous Studies – II

Unique Feature	Studies	Main Ideas and Considerations
Multiple Decision Factors	Boughton (1987)	Conducted a survey to identify multiple decision factors considered by U.S. general contractors.
	Mochtar and Arditi (2001)	Conducted a survey regarding current pricing practices. Found most contractors use intuition after subjective assessment on competition.
	Ahmad (1990)	Considered decision maker's preference over multiple business factors.
	Chua and Li (2000)	Considered underlying determining factors rather than the decision itself. Identified multiple decision factors for go/no-go decision.
Market-based Pricing	Mochtar and Arditi (2001)	Emphasized market-based pricing against cost-based pricing considering that actual winning a job depends on competition itself more than absolute level of price.
	Chao and Liou (2007)	Proposed a risk-minimizing approach for a contractor to determine the lower limit of the bid.
Other Approaches	Broemser (1968)	Developed a model for sequential bidding. Considered contractors' bonding capacity and loss of opportunity of future projects.
	Chen (1991)	Proposed a portfolio approach for multiple projects in bid decision considering correlations between projects.
	Han et al. (2004)	Proposed a portfolio approach for international projects focusing on financial risks.
	Christodoulou (1998)	Developed an artificial intelligence model using fuzzy artificial neural networks
	Lin and Chen (2004)	Developed a fuzzy linguistic approach to quantify and incorporate multiple qualitative factors

2.2 Missing Concept in Competition Studies in Construction

In construction, competition studies have focused on competitive bidding, which is the major mechanism of competition in the market where contractors obtain their jobs. Even though there have been numerous improvements since Friedman's original work, the previous competitive bidding models and proposed approaches are criticized regarding their difficulty in the implementation for real business (de Neufville et al. (1977), Shash (1993), Christodoulou (1998), and Fayek (1998)). By implementing new and additional ideas and considerations, proposed approaches come to have more sophisticate structures in decision process, but at the same time they have become more complex and difficult to implement in the real business decisions.

Competitive bidding studies emphasize the importance of bidding strategies to contractors, and they propose using quantitative analyses and measures to make the decision process objective and clear. However, in the real situations, subjective assessment is the most commonly used method by contractors (Shash, 1995). Many researchers agree that there are broad gaps between theoretical approaches proposed in the literature and application in the real situation (Rothkopf and Harstad, 1994). The criticisms relate to the static assumptions and the narrow perspectives taken.

There are important points that have not been fully considered in previous studies even though they could have significant effects on competition among contractors. They are:

- Risk-taking under competition is an essential element in the construction business: bidding is risk-taking since bidders do not know the true cost of job;

- Contractors may have their own risk attitude which affects organizational behaviors, in particular risk-taking behaviors. Risk attitude is a part of organizational culture and it is universal to all contractors;
- Competition is developed by multiple competitors. Result of a competition is always relative depending on competitors' risk-taking behavior. Ultimately, different risk attitudes among contractors could affect competition among themselves.

Previous studies have considered risk attitude as a single decision factor for an individual contractor's bid decision. Less attention has been paid to competition among multiple contractors that may behave differently in their risk-taking depending on their own organizational risk attitudes.

2.3 Competition Studies in Other Areas

This section provides literature reviews on competition studies in other fields such as biology, ecology, economics, management, and so on. Through the literature review, it searches for an efficient methodology for the current investigation.

2.3.1 Studies in Biology and Ecology

Since the theory of evolution was presented in a book, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for*

Life (1859), Darwin's scientific discovery has revolutionized biology. Also, various applications of his idea can be found in other scientific areas.

In his theory, natural selection occurs over successive generations among species in competition when there are heritable variations for some trait and differential survival and reproduction process associated with the possession of that trait. Individuals with favored traits survive and reproduce and their offspring inherit parents' traits that influence success in survival and reproduction. Next generations consist of a higher proportion of individuals that possess the favored traits, while others without the favored traits disappear (Allan, 2005).

In biology and ecology, competition is one of the key issues. Studies in these areas discuss competition within a species or between species as the relationship between individuals who compete for common living requirements, such as energy or space (Carbone and Gittleman (2002); Marquet (2002)). Individuals' energy consumption and limited resources are considered as basic elements of competition and the selection evolves through competition (Marquet (2000); Schmid et al., (2000)). One may find an analogy in the construction business to this biological phenomenon in the nature: contractors competing with each other for common job opportunities available in the market.

2.3.2 *Competition and Mode of Competition*

Keddy (1989) provides a broad definition of competition as “The negative effects which one organism has upon another by consuming, or controlling access to, a resource that is limited in availability.”

Competition is classified into different modes. Depending on the mechanism in it, competition is categorized as below (Molles, 2005).

- Interference competition: it occurs directly between individuals via aggression when the individuals interfere with each other. For example, three-spot damselfish, which inhabit lagoons and coral reefs, guard a certain territory and intensely compete for space between individuals.
- Exploitation competition: this competition occurs indirectly through a common limiting resource. For example, individual plants in a local population consume more amounts of nutrients, water, and space as they grow while the resources are limited. Direct interactions are not obvious as much as the interference competition, but the competition occurs underground where the roots of plants compete for the resources.
- Apparent competition: it occurs indirectly between two species when both of them are preyed on by the same predator. For instance, species *A* and species *B* are both prey for predator *C*. The increase of species *A* will cause the decrease of species *B* because the increase of *A* increases the number of predator *C*s which in turn will hunt more of species *B*.

The above competitions also can be classified into direct and indirect competitions. In addition, the classification applies equally to intraspecific and interspecific competition. Intraspecific competition occurs when members of the same species compete with each other for the same resources in an ecosystem. Interspecific competition occurs when individuals of two separate species share a limiting resource in a same area.

It is not easy to define one specific type of competition for the competition in the construction market. Contractors compete with each other for common job opportunities similar to the exploitation competition. But, sometimes, contractors may try to prevent their competitors' expansion to their current market segments, which would be similar to interference competition. A contractor's competitive strategy could be directed against its competitors or less specific just considering general competition in the market place.

Meanwhile, many contractors in the construction industry are often considered simply reactive since clients initiate construction projects and contractors do not have much control over their jobs (Ramsay, 1989). Due to this reason, Ramsay (1989) maintained that some aspects of business strategy developed mainly for manufacturing industries that have relatively higher control over their products in the market are not suitable for the construction industry.

2.3.3 *Empirical Findings*

Probably, it is considered quite obvious that small organisms generally live at higher population densities than larger ones. But, why does this phenomenon evolve?

Damuth (1981) questioned the relationship between population density and organisms' body size and found that the population density of 307 species of herbivorous mammals decreases with increased body size. In a log-log plot of population density against body size, he found an apparent straight linear trend. He asserted this general rule can be applied to individual species.

Peters and Wassenberg (1983) extended Damuth's study (1981) to a greater variety of animals: including invertebrates, aquatic invertebrates, mammals, birds, and poikilothermic vertebrates. Their study confirmed the findings by Damuth (1981). They found some differences in the slope of the linear trends between species in log-log plots, but the overall patterns are similar to each other.

In these empirical studies, researchers in biology and ecology have found a ubiquitous phenomenon in a variety of systems: the power law (Marquet (2002); White and Seymour (2005)). According to the study results, dimensional analysis of the relationship between population density (D) and body size (mass, M) finds an exponential relationship as in Equation 2.4.

$$D = \alpha M^{\beta} \text{ or } \log D = \alpha + \beta \log M \quad [2.4]$$

The relationship is linear on a logarithmic scale. The value of β is negative, indicating an inverse proportionality (Schmid et al., 2000): population density decreases as body size increases, *and vice versa*. Many ecology studies reported β values around $-3/4$ (Damuth (1981); Peters and Wassenberg (1983)), but there are differences of

opinion and different values have been found (Schmid et al. (2002); White and Seymour (2005)). Figure 2.2 provides an example of power law in nature, captured from Marquet et al. (2005). In the figure, open circles represent primary consumers (herbivores) and filled circles represent secondary consumers (carnivores). Note the scatter in Figure 2.2: even though power law applies in the aggregates, different species have different parameters α and β .

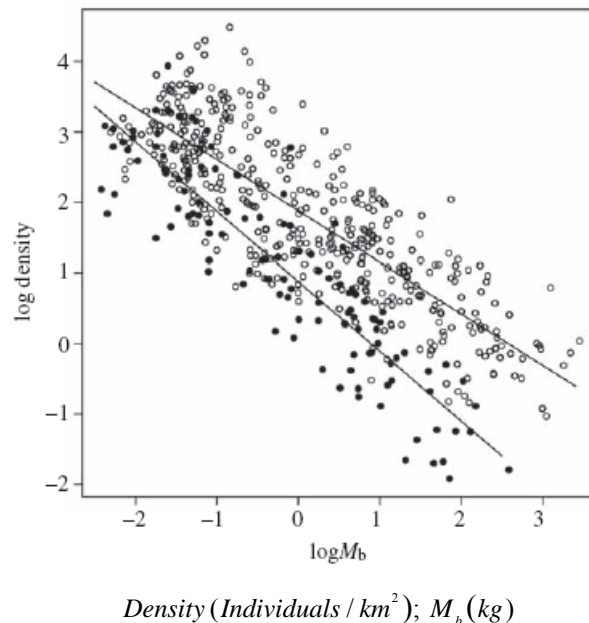


Figure 2.2 Power Law in Mammalian Population (Marquet et al., 2005)

Marquet (2002) describes the power law as below.

“Energy that organisms need... scales with body mass... A limited amount of available energy per unit will sustain a larger number of individuals of a small-sized species than of a bigger species... Assuming energy limitations, population densities of

large species are expected to be lower than those of smaller ones because of their higher total metabolic demand...”

A fundamental interpretation of power law is from Kleiber’s law: the amount of energy that organisms need to sustain themselves, metabolism, scales with body mass according to $Metabolism \propto (Body\ Mass)^{3/4}$ (Marquet, 2002). Individuals’ rate of resource use and availability of resources are considered as critical factors in the development of the power law (Carbone and Gittleman, 2002). The existence of the power law has been found in various areas other than biology and ecology. Examples of the power law include the frequency of earthquakes of different magnitudes, the distribution of individual incomes, and the size distribution of organizations.

2.3.4 *Studies in Economics and Organization Theory*

In economics and market ecology, researchers have applied the biological competitive relationship to the population of economic organizations (firms) or individuals in the market place to identify mechanisms that construct some aggregate pattern or phenomenon in different industries (Singh, 1990). One of the promising methodologies that have been applied in these areas is the evolutionary approach.

Schumpeter (1912) presented the first evolutionary theory of economy in his book, *Theory of Economic Development*. The critical idea in his theory is *creative destruction* based on innovation in economic organization. The innovation is defined as an evolutionary process which creates new markets while destroying existing organizations. The extinction of the horse and buggy industry due to the birth of the

automobile industry is an example. Schumpeter's evolutionary theory considers organizations as individuals that initiate innovation, which is considered as an exogenous variable in neoclassical economics.

There are two opposing forces in his evolutionary theory: *adaptation* and *innovation*. Adaptation is a process in which a market becomes stable. Stability through adaptation is a conservative force in a market. Opposing to the adaptation process, innovation is a disruptive force but endogenous (generated by organizations themselves). The entrepreneur disturbs the stability by his or her innovation. If the innovation is successful, the entrepreneur creates new value and this success induces others to follow, which leads to a new adaptation process. Organizations that succeed in the adaption survive and others that fail disappear (Summers, 1997).

Nelson and Winter (1982) led the development of an evolutionary approach. They published a book, *An Evolutionary Theory of Economic Change*. Nelson and Winter argue that a firm's behavior is determined by the firm's routines, which play the central role similar to the genes in biological evolution. A firm's routine is a persistent organizational feature that defines how they do business, and it governs the firm's behavior. They maintained that firms may have different routines and some firms outperform others due to better routines, which derive selective force in competition in a market.

On the other hand, in organization theory, the two major mechanisms of changes in business organization are discussed in the literature: adaptation and selection (Singh, 1990). Earlier studies in organization studies emphasized adaptive change in business

organizations: organizations themselves modify their features to fit with environmental conditions. Later, a selection approach by Hannan and Freeman (1977) has become dominant in this field of study (Singh, 1990).

Hannan and Freeman (1977) proposed a population ecology perspective focusing on the mechanism of selection as an alternative to adaptation perspective. They criticized the overemphasis of adaptive capability of organization. According to them, organizations have limited ability to adapt. Structural inertia in organizations restricts the organizations' adaptive flexibility. In addition, the organization's capability to adapt is also subject to systematic selection through the competition among organizations in a population.

These conflicting concepts between adaptations and selection have brought different views on the major mechanisms of organizational changes. Scott (1987) asserted the two mechanisms are not incompatible, but complementary. According to Scott, the selection mechanism is more favored by the population ecology while the adaptation mechanism by the resource dependency approach in which organizations are viewed as more active in determining their own fate than population ecology. He maintained that the selection in population ecology is efficient to study *core* features (directly related to organization survival) of organizations, survival of smaller and more numerous organizations, and changes in organizational forms over long periods. Meanwhile, resource dependency approach that favors the adaptation mechanism emphasizes *peripheral* (non-core) features of organizations.

Meanwhile, Levinthal (1991) maintained that the two mechanisms for organizational changes are not mutually exclusive, but interrelated. Organizational changes generate two types of risks; 1) uncertainty of the change (adaption) and 2) uncertainty regarding the organizational fitness (selection). These two types of uncertainties are interrelated. Adaption process affects organizations' survival by making improvements presumably through organizational learning while reorganization against environmental changes to survive can accelerate organizational failure, which relates to selection process.

The studies have proposed different concepts on evolutionary process in a market. Regardless of what mechanisms were adopted in these studies, the common goal of these studies is to understand the mechanism of organizational changes in a market. The changes of interests include organizational birth, death, expansion (growth), contraction, and aggregate patterns or effects that emerge at the population level. These studies consider the identified patterns as resultants of competition among individuals in a population and investigate underlying mechanisms of them.

2.4 Size Distribution of Firms

Economic researchers have questioned the hidden mechanism of the invariant phenomena in industrial structures, i.e., shapes in the size distributions of business organizations in different industries. The findings are so widespread in different industries that researchers named these phenomena '*stylized fact*.' Meanwhile, however

there are also many empirical findings different from the '*stylized fact*' (Kwaśnicki, 1998). The size distributions of firms in the question are usually highly skewed, but economic theory does not explain much about these observations (Simon and Bonini, 1958).

Literature review on the size distribution of business firms finds that there have been different explanations about the hidden mechanism questioned, but not confirmed:

- Long-run average cost curves;
- Gibrat's law of proportionate effect;
- Allocation of scarce factors of production; and
- Evolutionary process among heterogeneous organizations.

Among these explanations, some of them already lost validity of their explanations due to the conflicting evidence found in later empirical studies. Dispersed ideas are discussed in the literature for the explanations without provision of a confirmative answer. Following is the description of the historical reviews on the relevant studies about the size distribution of business organizations in the economic market.

2.4.1 Approaches Using Long-run Average Cost Curves

It seems that the first effort to explain the size distribution of firms was by Viner (1932). He proposed a theory of firm size using the concept of long-run average cost curves (LRAC). His theory says that individual firms have U-shaped long-run average cost functions as they increase their production: economies of scale are effective up to a

certain amount of production, but diseconomies of scale prevail as production increases beyond a certain point. So, there is the optimum level of production to have minimum unit cost per production.

Based on the theory, firms produce at the minimum point of the curve while adjusting total industry production to market demand and at the aggregate level of a market, the size distribution of firms evolves through the allocation of production over firms to minimize total cost. However, Viner's theory has been weighed down by different explanations on the size distribution of firms proposed by the later studies (Lucas, 1978), which include following.

2.4.2 *Stochastic Approaches Using Gibrat's Law*

Simon and Bonini (1958) proposed a new approach to the question. They presented a stochastic mechanism using Gibrat's law (1931) for firm growth to explain the highly skewed distribution of firm sizes. The law states that the distribution of percentage changes in size of firms in a given size class is the same for firms in all size classes (Simon and Bonini, 1959). Therefore, the rates of firm growth are independent of firm size. The law can be explained using Equation 2.5 below:

$$x_i(t) = \alpha + \beta_i x_i(t-1) + \varepsilon_i(t) \quad [2.5]$$

Where, $x_i(t)$ is the log size of firm i at time t ,

α is a growth component common to all firms, and

ε is i.i.d (independent and identically distributed) random terms.

For all i , β_i is equal to 1, which means the expected rate of growth is independent of the current size of firms.

After Simon and Bonini (1958), different stochastic models have been proposed. However, many of them simply applied modified forms of Gibrat's law of proportionate effect (Ijiri and Simon, 1967). Empirical findings in later studies have challenged Gibrat's law. Some empirical studies found that firm growth rate and their variations somewhat relate to firm size and age. Meanwhile, other studies show small size firms grow faster and have low survival rates (Jovanovic (1982); Dosi et al. (1995)).

2.4.3 *Equilibrium Approaches*

Some later studies proposed different approaches that do not rely on Gibrat's law. These studies consider the stability in size distribution of business firms as a realization of equilibrium in a market. Lucas (1978) considered the stability in size distribution of firms as a competitive equilibrium. He maintained the size distribution of firms emerges based on underlying distribution that is derived through optimum allocation of managerial talents and production factors across managers over firms while maximizing total output. The proposed approach is resource-based. In the model, a firm is defined as a collection of assets and the matching of managers (managerial talent) to asset collections can change over time periods.

Similarly, Jovanovic (1982) considered competition and resultant market selection among heterogeneous individuals (they are different in terms of efficiency in production) as a process toward equilibrium. Firms make production decisions under

imperfect information to maximize expected profits in an industry with a homogeneous output. Both studies by Lucas (1978) and Jovanovic (1982) provide mathematical solution for the equilibrium problems.

2.4.4 Evolutionary Approaches

Recent studies have applied evolutionary approaches to model competition. Dosi et al. (1995) questioned the invariant phenomena observed in a population of organizations: the invariant size distribution of organizations, the persistence of asymmetric firm performances, and the dynamics of entry and exit. They developed an evolutionary model in which firms perform technical learning and competitiveness of a firm in a market depends on its learning. Major features in the model can be summarized in Table 2.5.

Table 2.5 Main Features in the Evolutionary Model by Dosi et al. (1995)

Features	Descriptions
Firms' Learning	<ul style="list-style-type: none"> Firms perform technical learning through a stochastic process.
Heterogeneity among Firms	<ul style="list-style-type: none"> Heterogeneous firms have their own competitiveness, which is dependent on firms' learning and the level of market selection specified in the model.
Firm Size	<ul style="list-style-type: none"> Market share of a firm is relatively decided using the firm's own competitiveness and the industry average competitiveness, which is affected by the degree of market selection.
Firm Exit	<ul style="list-style-type: none"> An exit occurs when an individual firm's competitiveness is below a certain level or its market share falls below a certain minimum level.
Firm Entry	<ul style="list-style-type: none"> The number of entrants is random but proportional to the number of incumbents allowing possible spin-offs from incumbents. Entrant's competitiveness is randomly decided, but affected by level of entry barrier and level of opportunities in the market.

As recognized in Table 2.5, their evolutionary model requires specification of multiple model parameters which are qualitative such as the degree of market selection, the degree of entry barrier, and the level of opportunities in the market. Dosi et al. (1995) maintained that the regularities in industrial structures are emergent properties derived through non-equilibrium interactions among heterogeneous firms that perform technological learning.

Kwaśnicki (1998) developed another evolutionary model to investigate the stability in skewed size distribution of firms relying on the genetic algorithm for the evolution process. In his model, individual firms have their own *routines* and pursue innovations by spending research and development (R&D) funds. Thus, this model basically follows Schumpeter's idea of creative destruction in the evolutionary process using innovation as driving force. Individual firms make their own decision on price, production, and investment in a competitive environment. Success in the search for innovation depends on R&D funds spent as well as publicized knowledge (firms publicize their own technique to the public, which enhances overall technology level in the market).

Table 2.6 summarizes the main features in the evolutionary model. Kwaśnicki (1998) asserted that the evolutionary process through the innovations in cost reduction and/or improvement of product technical performance results in the skewed distributions without specifying any role of economics of scale (i.e., the long-run average cost curves) and any rules for firm growth rates (i.e., Gibrat's law). Since construction firms do not

spend significant research and development funds, the evolutionary mechanism in Kwaśnicki's model is not applicable for construction firms.

Table 2.6 Main Features in the Evolutionary Model by Kwaśnicki (1998)

Features	Descriptions
Firm's routine	<ul style="list-style-type: none"> ▪ Firm routine decides variable costs of production, productivity of capital, and product characteristics for the firm. ▪ The routines function like genes as in biology. ▪ Firms' routines evolve over time periods through mutation, recombination, transition, and transposition.
Firm's decisions	<ul style="list-style-type: none"> ▪ Individual firms make predictions about future markets. ▪ Individual firms make decisions on price, production, and investment based on their own expectations expected profit and previous performances to maximize own objective functions.
Innovation	<ul style="list-style-type: none"> ▪ An innovation occurs in unit cost reduction, growth of productivity of capital, and improvement of the product's technical performance.
Entrants and exits	<ul style="list-style-type: none"> ▪ A firm enters the market when its expected value of its objective function is greater than industry average. ▪ A firm exit occurs in the opposite condition among existing firms.

As found in the relevant studies, some entities having a better trait survive and others disappear in a competitive market. However, in theoretical foundation, there are still disagreements: organisms influence their own environments and selection regimes, therefore in such cases boundaries between environmental development and organizational selection are not clear (Erwin and Krakauer, 2004). There is a need of such competition study for construction contractors.

2.5 Discussion and Lessons from Other Competition Studies

Competition studies in other areas provide more comprehensive perspectives on competition in a population of organizations than the competition studies in construction that mainly focused on competitive bidding while taking narrow or individual perspectives. The comprehensive views are favored in investigating competition in a market or a population since they consider changes in organizational life-cycle (birth, expansion, contraction, and death) and aggregate industry patterns, which are resultants of competition. Organizations' expansion, contraction, and death are derived by a selection process that decides winners and losers in the market place. The selection evolves through competition among individual organizations in a population.

Especially, evolutionary approach is considered as one of the promising methodologies that can be used for the current investigation since it allows more comprehensive and long-term views on competition among contractors. In the evolutionary approach, winners survive and prosper since they possess something unique compared to losers.

Most of previous studies in construction missed an important question: *How is success of a contractor defined?* Friedman (1956) specified the objective of a construction contractor in his model as maximization of total wealth of the firm. However, there is no specific representation of the maximization of firm wealth in the model. Later models adopting the same conceptual framework also assume similar objectives for a firm. Since the objective of these models is finding optimum markup or

bid amount for an individual firm for a job, their perspectives are narrow and limited. In these studies, success of a firm is defined for a short-term.

However, winning one profitable job does not guarantee a firm's success. Success can be attained through profitable and continuous business operations over time periods while competing with its competitors in a market place. This fact is more critical in construction where contractors themselves do not generate market demand and they compete with each other to obtain job opportunities available in the market. In the market, competition decides winners and losers. Success of a firm should be analyzed within the domain of competition in a market place considering a long-term time frame, not for a single job.

2.6 Summary

Chapter II reviewed competition studies in construction as well as in other areas such as biology, ecology, economics, and management. First, as to the competition studies in construction, they have focused on contractors' decision problems in competitive bidding. Various approaches and models have been proposed for better solutions; however there are still vacancies to be filled as summarized in Section 2.2. The missing concept can be filled out by investigating the effects of risk attitude.

On the other hand, as to the competition studies in other areas, different mechanisms for organizational changes and industry evolution have been studied. One of common approaches in these studies is analyzing empirical patterns externally

observed in different populations and figuring out the underlying mechanisms of the aggregate patterns. The patterns are considered as resultants of competition among individuals in a population. Relevant studies have investigated different organizational factors as hidden mechanisms or driving forces. They include organizational innovation (Nelson and Winter (1977); Kwaśnicki (1998)), organizational learning, adaptation, or mutation (Fiol and Lyles (1985); Levinthal (1991); Dosi et al. (1995)), and so on.

Most competition studies in construction can be criticized due to the static assumptions and the narrow perspective. One needs to take a new and comprehensive perspective on the competition among heterogeneous contractors in risk attitude and their success in the market. Competition studies in other areas provide new perspectives that have been not considered for the construction industry: broader view on a population of multiple individuals competing with each other and long-term view on an organization's life cycle. Success of a contractor needs to be defined within competition and analyzed for the long-term.

Most of competition studies in other areas have been performed for other industries, mostly manufacturing industries. To fill the missing concepts in the competition studies in construction and to have a better understanding of contractors' competition in the industry, the current investigation needs to be conducted for the construction industry by considering the unique characteristics of the construction business.

CHAPTER III

RISK ATTITUDE AND FIRM PERFORMANCES

Chapter III reviews studies on organizational risk attitude and firm performances and discusses the construction industry characteristics and contractors' business failure. The discussion reveals the criticality of contractors' risk-taking behavior and competition in the construction business.

3.1 Organizational Culture and Risk Attitude

In management and organization studies, organizational culture has been studied to identify relationships between organizational culture and individual firms' performances. This section reviews the relevant studies.

3.1.1 Organizational Culture

Organizations develop their own culture. Organizational culture is considered as an organization's inherent characteristics that govern its business pattern or behavior. Culture of an organization is a trait that characterizes the organization. Studies found that culture varies across organizations, even in homogeneous industries (Chatman and Jehn, 1994).

Many organization studies have been conducted to figure out what organizational cultures are, why organizations have different cultures, how culture affects individual firm's behavior and their performance, and whether organizational culture can be a source of competitive advantage (Barney (1986); Camerer and Vepsalainen (1988)). These organization studies are based on the intuitive idea that an organization will perform better when its employees are highly motivated and dedicated to common goals under its culture. One general hypothesis in organizational studies is that strong culture enhances firm performance (*Sørensen* , 2002).

Barney (1986) asserted that a firm's culture can be a sustainable competitive advantage if the culture is valuable, rare, and imperfectly imitable. Firms are expected to be effective if they have the right traits that fit to other organizational features within an organization that include structure, systems, and people. However, cultural risks evolve if they do not match (Schwartz and Davis, 1981).

Definitions of organizational culture are divergent and competing in the literature (Barney, 1986). Following are examples of definitions of organizational culture and characteristics of organizational culture available in the literature.

Barney (1986) defines organizational culture as “It is typically defined as a complex set of values, beliefs, assumptions, and symbols that define the way which a firm conducts its business.”

Schein (2004) defines organizational culture as “A pattern of shared basic assumptions that was learned by a group as it solved its problems of external adaptation and internal integration that has worked well enough to be considered valid and,

therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems.”

According to Schein (2004), organizational culture has the following four major characteristics: 1) structural stability; 2) depth; 3) breadth; and 4) integration and patterning. Each of them can be shortly described as below.

- Structural stability: an organizational culture becomes a stabilizing force within an organization when the organization develops its own sense of group identity. Then, it is difficult to give up the culture developed.
- Depth: organizational culture is less tangible and less visible because it is the unconscious and deep part of a group. Therefore, outsiders would have difficulty to figure out others’ organizational culture.
- Breadth: organizational culture is so pervasive that all aspects of organizational activities are influenced by it.
- Integration and patterning: organizational culture integrates organizational climate, values, and behaviors together into a whole while developing patterns within an organization.

In short, organizational culture deeply governs organizational activities through integration and patterning the organization’s behaviors and rationales while developing organizational stability so that it is not easy to change. These definitions and characteristics remind one of the firms’ *routines* in Nelson and Winter (1982) discussed in Chapter II.

Based on the above definitions and the characteristics of organizational culture, organizational culture plays critical roles in an organization. In that, many studies have been conducted to identify the relationships between organizational culture and firm performance: what differences in culture among firms exist and how the differences explain variations in performance among the firms.

However, it is very difficult to quantify or measure organizational culture of individual firms. Calori and Sarnin (1991) explain the difficulties in studying the effects of organizational culture on firm performance as “the evaluation of organizational culture requires in-depth and long-term longitudinal studies for individual firms and it requires a large sample size to derive a statistically meaningful result.” Due to the difficulty, questionnaire survey has been favored in many empirical studies.

Calori and Sarnin (1991) performed a limited case study using a questionnaire survey for five French business firms. They surveyed 260 individuals in the five firms regarding individual perceptions on organizational practices to investigate the relationship between firm culture and performances. In their study, firm performance was measured based on return on investment, return on equity, and return on sales using financial data of the firms. They found that the intensity and homogeneity of the firm culture are positively correlated with firms’ relative growth and also that some cultural attributes and associated management practices are positively correlated with firms’ performance. However, their study is limited due to the small number of firms.

Chatman and Jehn (1994) also performed a questionnaire survey to figure out whether differences in organizational culture exist between industries. It aimed at

identifying relationships between organizational culture and different industry characteristics. Levels of technological innovation and growth rate were assumed to be the major differences in industry characteristics. The questionnaire survey was conducted for fifteen U.S. firms in four different industries, which however are all service industries. Surveyed firms are major players in their industries. The survey results found that industry membership accounts for differences in organizational culture of firms, but with high variance. They could not confirm any causal relationship between organizational culture and the industry characteristics, i.e., growth and innovation which they assumed as major differentiators.

Sørensen (2002) questioned environmental effects regarding organizational culture. He viewed organizational culture of a firm as the product of histories of organizational learning over time periods and future capability in learning. Assuming that strong culture would not be efficient in adaption since strong culture cannot be easily changed, *Sørensen* hypothesized that the relationship between firms' performance and firms' culture would depend on different environmental conditions. Relying on a previous study by Kotter and Heskett (1992) which was a questionnaire survey for multiple firms on the cultural strength of organizations, *Sørensen* (2002) combined his analysis on firms' performances using COMPUSTAT data with Kotter and Heskett's survey results. *Sørensen* found that firms that have strong cultures have less variable performance than other firms in stable business environments while the benefit of strong culture decreases as environmental volatility increases.

Despite some differences in findings, these studies identify the existence of the effects of organizational culture on firm performances focusing on the strength of organizational culture and differences in industry characteristics.

3.1.2 *Organizational Risk Attitude*

Schein (2004) provides another definition of organizational culture, “the accumulated shared learning of a group covering behavioral, emotional, and cognitive elements of the group members’ total psychological functions.” Then, organizational risk attitude, a part of organizational culture, can be defined as a shared preference toward uncertainties, covering behavioral, emotional, and cognitive elements in an organization’s business decisions and activities when the organization faces uncertain situation.

Organizational risk attitude is also subconscious within an organization. Hillson and Murray-Webster (2005) provides a definition of risk attitude, “*a chosen state of mind with regard to uncertainties that could have positive or negative effect on objectives ... risk attitudes are usually adopted sub-consciously.*”

The risk attitude of an organization defines what risks can be accepted and what risks cannot be accepted within the organization. In a risky situation, individuals or organizations perceive the situation in their own ways, which are affected by their own risk attitude. Therefore, depending on their own perceptions, individuals or organizations may make different responses even to an identical uncertain situation.

It has been recognized in the literature that individuals and organizations may have different risk attitudes. Traditionally, the differences in risk attitude have been represented using utility theory and utility functions (von Neumann and Morgenstern (1944). Walls and Dyer (1996) and Pennings and Smidts (2000; 2003) found the presence of heterogeneity in risk attitude using utility functions among petroleum firms and agricultural organizations, respectively.

Pennings and Smidts (2000) assert that different risk attitudes can explain the differences in how firms do their businesses based on their computer-assisted interviews of 346 Dutch owner-managers of hog farms. The study measured different risk attitudes among firms and identified/categorized different ways the firms conduct business in terms of risk management. They found that risk-averse managers appear to be less innovative and more intent on reducing fluctuations in net income and profit margin. Similarly, Pennings and Smidts (2003) found differences in utility functions among the different managers based on measurements among 332 owner-managers.

In management, many studies assume that business managers are somewhat risk-averse. Meanwhile, there are researchers questioning the assumption of global risk-aversion (Fiegenbaum and Thomas, 1988). However, in general the literature provides evidences of heterogeneity in risk attitude among organizations (Walls and Dyer (1996); Pennings and Smidts (2000, 2003)). These findings of heterogeneity in risk attitude and resultant differences in the ways they do business lead to other research questions about the relationships between risk attitude and firm performance.

3.2 Strategic Management Studies

Strategic management studies in this review focus on firm performances with respect to firms' risk-return association and diversification. Organizational risk-taking and its effects on firm's performance have been critical issues in strategic management (Bromiley, 1991). There are a significant amount of studies investigating risk-return association, mainly focusing on relationships between average returns and variance in returns. Also, related studies have been performed about firms' diversification as a corporate strategy for growth and risk management.

3.2.1 *Risk-return Association*

Question in the management studies about risk-return association is how much firms earn at what levels of risk in their investments. These studies have tried to identify relationships between firms' average returns and variance in the returns using firms' historical data.

Earlier studies found positive correlations between average returns and variance (heteroskedasticity) in the returns, which was presumably based on conventional wisdom in economics (Fiegenbaum and Thomas, 1985). However, recent empirical results have been varying and conflicting. Some studies found positive relationships while others found negative or non-significant relationships. As explained in detail below, different studies provide controversial results depending on the data used, time periods covered by data, and measurements applied in their analyses.

The series of finding negative relationships in risk-return association have been led by Bowman (1980). Bowman (1980) found negative relationship between the level of return and variance in the returns. His analysis found that low performance firms take more risks (later studies name it *Bowman's Paradox or Risk-return Paradox*). It is a paradox since risky tasks or jobs are supposed to be more profitable in order to be attractive to firms: higher profits are expected to be associated with high risks (greater variances): positive association. Before Bowman, most of previous empirical studies reported positive relationships.

On the other hand, Fiegenbaum and Thomas (1985) found the relationship in risk-return association to vary over time. In their analysis using COMPUSTAT data, they found that the relationship was negative during the first time period (1960s) and it was positive during the second period (1970s). In addition, they found differences in the risk-return association in different industries, which lead to questions about underlying factors related to industry specific environment and characteristics.

Fiegenbaum and Thomas (1985) showed instability of relationship depending on data periods as well as instability of results using different risk measures: accounting-based measure (average ROE and ROE variance) vs. market-based measure (variance in returns to market investors). Based on these variant results, they asserted that the studies on risk-return association depend on the measurement of risk applied in analysis. They pointed out the problem in *ex-post* measure of risk (variance in realized results) while risk is an *ex-ante* concept.

In many empirical studies using actual data, risk is usually measured as variance of outcome (*ex-post* measure). However, a decision is made before the outcome is realized (*ex ante*). Therefore, the measurement of risk in these studies is variability of realized outcomes, not risk that a decision maker perceives at the time of decision making.

Bromiley (1991) applied a different approach to risk measurement. He developed a dynamic model that constitutes two multiple regression sub-models (risk model and performance model) which have lagged variables to investigate the relationships between the amount of risk taken by firms and firm performance. He measured, for an *ex-ante* measure of risk, variances in the securities analysts' forecasts of earnings per share for the year instead of using the conventional measure of risk (*ex-post*: variances in realized returns). Two sources of data were used: accounting data from Standard and Poor's COMPUSTAT and the analyst forecast data from Institutional Brokers' Estimate System, IBES. The data cover 288 companies from 1976 to 1987. The result presents a causal relationship that states poor past performance increases risk-taking and the increased risk-taking results in another poor performance in next years.

Besides the studies discussed above, there are many studies on risk-return association, but providing controversial results. Fiegenbaum and Thomas (1988) provide an extensive survey of studies on the risk-return association by tabulating major studies historically performed. Their survey confirms the existence of controversies on risk-return association.

3.2.2 *Diversification*

The association of risk-return performance with corporate strategies, especially diversification as a risk management strategy, has been investigated in empirical studies for industrial organizations (Palepu (1985); Chang and Thomas (1989)). In many industries, it is easy to find that large firms usually diversify in their growth. However, there are somewhat divergent views on firms' diversification, as discussed below.

Diversification, especially market diversification, is a departure from a firm's current experience base and it can be a riskier choice than improving its current performance in the current market a specialized firm knows best. Meanwhile, in modern portfolio theory, diversification is described as a way to reduce risk and risk-averse investors are expected or want to be diversified (Rubinstein, 2002).

There have been many empirical studies on the relationship between diversification and firm performances. However, similar to the studies on risk-return association, no consensus has been reached about the relationship between firm diversification and firm performance (Pandya and Rao (1998); Chang and Thomas (1989)).

In construction, there are a relatively very small number of strategic studies and most of them, unfortunately, borrow theories and recommendations directly or indirectly from management studies. Regarding firm diversification, there are few studies. Nevertheless, following are several studies in construction regarding to firm diversification as a corporate strategy.

For construction, Heney (1985) asserted that the best strategy for construction firms would be the combination of specialization and diverse market segments. In addition, Tasi (1994) developed multiple regression models using the data of 100 construction firms and concluded that specialization would be favorable to maximize expected return while diversification would result in lower risk. However, Choi and Russell (2005) performed a longitudinal data analysis using 12 years' data of 108 public construction firms and found no significant difference in performance between high and low diversification firms.

On the other hand, there are many studies regarding the relationship between firm diversification and performance for other industries. However, their study results also vary. Palepu (1985) found no significant profitability difference between firms with high and low diversification using data of 30 firms from the food products industry. Chang and Thomas (1989) also found no significant difference and suggested that firm size better explains the differences in firm performance than diversification, using data of 64 firms (in multiple industries) from the COMPUSTAT database.

There are more instances showing controversial results. Gort (1962) examined diversified firms' profitability using 111 large U.S. firms and found no significant relationship between diversification and firm performance. On the contrary, Pandya and Rao (1998) found using a large sample of firm data (about 2,000 firms in multiple industries from the Compustat database) that the group of diversified firms tends to perform better on average, but the best performing firms are specialized. Also, they

found that specialized firms show higher performance in average return on equity, but they have high volatility in performance comparing with the diversified firms.

3.2.3 *Limits of Empirical Studies*

Previous empirical studies provide controversial results. Chang and Thomas (1989) maintained that a causal linkage between diversification strategy and risk-return performance is still not confirmed, and they proposed to consider managerial risk attitude for future studies.

Walls and Dyer (1996) pointed out a critical problem in the empirical studies on risk-return association. Risk is usually measured as variance of outcome (*ex-post* measure), which becomes available after the outcome of an event is realized. But, a decision is made before the outcome is realized (*ex-ante*). It is difficult to figure out how the decision maker perceived a risky situation and made a decision at the time of decision making. This problem has been discussed in the literature by other researchers (Bowman (1982), Fiegenbaum and Thomas (1985, 1988), and Bromiley (1991)).

Thus, empirical studies using ex-post measures have limitations and their results may be unreliable. To resolve this problem, Walls and Dyer (1996) reconstructed risky alternatives that firms might have considered at the time of investment decision using the historical data of petroleum firms. As a result, they derived an inference of the relationship between firm performance and risk attitude: moderately risk-taking firms show better return on assets.

Most of strategic management studies have been performed for other industries than construction. Unfortunately, in construction, it is difficult to find longitudinal data on contractors' performances since many contractors are privately owned and do not publicize their business information. The current study performed a data search to find that only a small number of construction firms' financial data are available in COMPUSTAT database, which have been frequently used in many strategic management studies discussed above.

3.3 Characteristics of the Construction Industry

As found in the literature review in Chapter II, there have been many studies on competitive bidding for construction contractors. However, there are relatively small amount of studies focusing on other industry level problems and other aspects of competition in the industry. Meanwhile, strategic management studies on relevant issues have been conducted for other industries than construction. As Ramsay (1989) asserted, some aspects of business strategies developed for manufacturing firms have little relevance to construction contractors.

Characteristics of the construction industry differentiate the industry from most other industries (Hillebrandt and Cannon, 1989). The current section discusses unique characteristics of the construction industry and reviews the industry level problems with respect to competition. It is valuable to review the unique characteristics of the

construction industry since it helps understand the criticality of construction contractors' risk-taking and competition in the construction industry.

3.3.1 Fragmentation

The construction industry is highly fragmented (Drew and Skitmore, 1997). Consider other industries such as car manufacturing industry. There are a relatively small number of firms occupying large shares of the market. Comparing to this type of industries that have high levels of concentration, in construction, even the largest firms are small in their shares of the market (Broemser, 1968). Why there are not such large construction firms?

A market structure evolves through competition in a market. In economics, market structure, or called market form, describes the state of a market regarding competition within the market. In theory, different conditions of competition in the market are described by monopoly, oligopoly, perfect competition, and monopolistic competition (Forgang and Einolf, 2006). In monopoly, only one provider occupies a market. In oligopoly, a small number of firms own major percentages of the market share. In the opposite of the monopoly, perfect competition describes a market where there are a very large number of firms compete with each other producing a homogeneous product. Monopolistic competition describes a market where there are a large number of independent firms which have a very small proportion of the market share and the competition is not focused on pricing.

In the construction industry, there are a large number of firms occupying a very small fraction of the market share. Some similarities are found in perfect competition and monopolistic competition for the construction industry. However, the both descriptions do not exactly fit to the construction industry. In construction, every construction project is different and unique, information in the market is not perfect, and a competition occurs among multiple contractors for a job that is initiated by one client, while pricing is one of the most frequently used marketing strategies by contractors in the competition.

In this fragmented market, contractors (producers) do not have control over their jobs (products) as much as other manufacturing firms have. Possible reasons for the fragmentation of this industry include the low entry barrier in the construction business. The low entry barrier allows many new entrants to a market, which raises the level of competition unless the available job opportunities increase in the market.

3.3.2 High Entry and Exit Rates

The construction industry is one of the weakest industries with respect to corporate insolvency risk (Hall (1994); Power (2002)). The construction industry is infamous for high exit rates. According to Dun and Bradstreet's 1997 data, business failure rate was 88 among 10,000 firms for the all U.S. industry and it was 116 for construction (Koksal and Arditi, 2004). Meanwhile construction market has low entry and exit barriers (Drew and Skitmore, 1997).

Major causes of the high exit rate include low profitability, high level of risks, and severe competition in the construction business, and high dependency on general economic condition. The industry is subjective to general economic condition so that it is not easy for construction contractors to avoid the negative effects when there are unfavorable impacts in economy.

Also, it would be in part due to the high entry rate, which keeps increasing the total volume of the industry capacity even though the industry has the highest exit rate. Construction is a labor intensive industry. It is relatively easy to start a business with little or no capital, which causes the high entry rate. An increased industry capacity can cause a higher level of competition in the market when market demand does not increase enough.

3.3.3 Derived Demand

Construction business is sometimes described by its high dependency on general economic conditions since construction demand is a derived demand depending on general economic conditions. And, construction demand is usually considered to be relatively inelastic to changes in construction price (Rawlinson and Raftery, 1997).

Differently from other types of business which can create the demand for their new product or service, construction demands are not generated by construction firms and contractors only respond to the derived demand. About 99% of the work is from derived demand in the construction industry (Rice and Heimbach, 2007). In

construction, contractors obtain their jobs by contract. In contracting, contractors have limited control over their contracts (Ramsay, 1989).

Since every single project is essential input for firm's operation in construction business, acquisition of new contracts is a critical managerial function in a construction organization (Willenbrock, 1973). Contractors have to pursue for jobs available in the market (Rice and Heimbach, 2007). These facts and the large number of small firms explain the high level of competition in the construction market.

In general, there is a typical time lag between demand cycle and the industry capacity cycle due to imperfect information or forecast of market changes (Dearden et al., 1999). This time lag also can be exaggerated by firms' reluctance to shrink in size while desiring to grow. With changes in market demand, imbalances between industry capacity and market demand are observed in this industry.

3.3.4 High Risks to Contractors

Also, the industry is commonly characterized by high level of risks and low profitability due to high competition. With regard to the high level of risks in the business, owners are in most cases protected by bonding when contractors fail while contractors themselves have no such protection (Rice and Heimbach, 2007).

Contractors take risks in their business. Their compensations for delivering a complete facility are based on their winning bids, especially in competitive bidding environment. That is, the profits of a construction firm are not determined by that firm itself. They are determined by competition with the firm's competitors.

In order to win a job, contractors compete with their peers. In competitive bidding, price is the most critical factor in competition among contractors. Winning jobs with low bids lowers contractors' profitability, which is observed more often, especially when market conditions go down and so the level of competition becomes high.

3.3.5 Low Level of Innovation and Inefficiency in Learning

Industries differ in terms of the level of innovative efforts, how to pursue innovation, and significance of output from the innovation (Dosi et al., 1995). Pries and Janszen (1995) analyzed the 46 years historical data of Dutch construction to figure out the trend of innovations in the industry. They found that Dutch construction industry has experienced slow changes compared to other industries. In their findings, the major contributor of industry innovations is suppliers, not contractors. Over 70% of all innovations originate from supply industries. The findings by Pries and Janszen (1995) would be applicable to other countries since construction business is not significantly different between countries.

The low level of innovation and inefficiency in learning would be due to the unique characteristics of the construction business. At the project level, each construction project is a different mix of labor, materials, equipment, supervision, subcontracted work, etc. (Benjamin, 1969). A project is delivered by a cooperation of different organizations including general contractor, subcontractors, material producers and/or suppliers. The cooperation ends at the completion of the project and thus there exist no efficient learning mechanism. Hegazy and Moselhi (1995) pointed out the

limited exchange of information and the industry fragmentation for no agreed general rules for cost estimation among contractors.

An innovation, whatever it is (for example, a better risk management, a better estimation technique, or an innovative project delivery system), could be attained more and often when learning by industry participants is accumulated in an efficient way. However, it seems not easy due to the unique industry characteristics in construction. Also, any innovation developed by contraction firms cannot be appropriated by that firm because the knowledge is immediately available to the firm's competitors due to interchange of people. Hence there is no way to sustain competitive advantage from technology.

3.3.6 Risk and Competition, the Unchanged Characteristics

It is quietly sure that the construction industry has been and will change and improve by applying new materials, new construction methods, advanced project delivery methods, etc. However, there is one thing that has not changed: contractors have to deal with risks inherent in their jobs and they always face competition in the market.

Competitive bidding is the major mechanism where contractors compete with each other to obtain jobs. According to a questionnaire survey performed by Hegazy and Modelhi (1995) for large general contractors in the U.S. and Canada, the majority of the contractors obtain their jobs through competitive bidding, as shown in Table 3.1.

Overall, about 73% of the contractors obtain more than 50% of their work through competitive bidding.

Table 3.1 Work from Competitive Bidding

Percentage of Work	Percentage of Respondents
76~100% of work	46%
51~75% of work	27%
25~50% of work	17%
0~10% of work	10%

Of course, competitive bidding is not the only mechanism in which contractors obtain jobs in the construction market. There are different contract methods and project delivery methods. However, even in other methods, there are still competitions among contractors and contractors need to take risks in different forms. The other mechanisms usually involve some assumption of risks by the client.

The characteristics of the industry discussed in previous sections may be considered just as unfavorable phenomena in construction. However, one can see potential improvements and large opportunities by making risk management and competition strategy more efficient.

3.4 Contractors' Business Failure

Construction contractors' business failure has been seriously recognized. However, many business failure studies have been performed for other industries than

construction such as manufacturing industry. Many of failure studies aim at predicting individual firms' bankruptcy using firms' financial ratios.

The prediction models by Altman (1968, 1983) and Edmister (1971) showed good performance in predicting business bankruptcy for firms in other industries. The famous Altman's Z-scores have been tested in many empirical studies. However, there are criticisms on the usage of these models. From a manager's perspective, it would be too late to make corrective actions to avoid the predicted failure when the prediction is available.

In construction, Kangari (1988) reported that the major causes/symptoms of business failure in construction include bad economic performance, management incompetence and lack of experience, inadequate sales, loss of market and economic decline, and difficulty collecting from customers. He developed a macroeconomic model (a regression model) to predict business failures in the construction industry considering overall external factors influencing contractors.

Meanwhile, Arditi et al. (2000) found that about eighty percent of the construction business failures find their main causes in the budgetary and macroeconomic issues that include insufficient profits (26.7%), industry weakness (22.7%), heavy operating expenses (17.8%), insufficient capital (8.29%) and burdensome institutional debt (5.93%).

Some studies paid attentions to nonfinancial or organizational aspects. Koksall and Arditi (2004) developed a statistical model to predict construction firms' decline. From the analysis based on questionnaire survey, they found that organizational

structure, human capital issues, and strategic posture are important in evaluation of a construction firm's condition.

A recent study by Rice and Heimbach (2007) provides more advanced views on contractors' business failures. Differently from previous studies which identify "surface level causes", the study tried to reach a deeper understanding of contractors' failure by identifying "causal roots of failure." They performed an extensive study over a variety of sources including industry financial data, case studies, consulting reports, failure prediction models, executive interviews, etc. The study categorizes failure causes into four groups:

- General economic conditions;
- Nature of the construction industry;
- Culture and systems of the organization; and
- Mind of the contractor.

These factors are interacting with each other leading to contractor's failure. Notably, organizational characteristics such as culture of the organization and contractors' mindset are identified as critical factors. The mind of the contractor includes followings:

- Driven to grow and unwilling to contract: most contractors by nature desire to grow business and they are reluctant to contract in size.
- Numb to risk: getting insensitive to high risk in the construction business.
- Hyper-optimistic and overconfident: can-do attitude, they believe they can control the risks.

- Project manager vs. CEO: most leaders were former project managers or superintendents who do not have knowledge of business. This problem is usually found in small construction firms.

This in-depth reasoning for the contractors' business failure reveals that organizational culture and risk attitude are critical root causes that lead to surface-level failure factors that have been identified as major causes by many previous failure studies.

3.5 Summary

The chapter provides literature reviews of the organizational issues: organizational culture and risk attitude, and the strategic management issues: the relationships between firm performance and firm risk-taking behavior (risk-return association) and between firm performance and firm diversification (diversification as a corporate risk management). The reviews confirm that organizations have different risk attitudes. And, the risk attitude as well as environmental risk factors and competition governs an organization's business decision and risk-taking behaviors.

Many empirical studies have been conducted to identify the relationships between firm performance and risk-taking behavior and/or firm diversification in the market. However, unfortunately, these studies provide controversial results that vary depending on the data they used for the analyses. Major limits in these empirical studies are 1) measurement of risk (*ex-ante* measure vs. *ex-post* measure) and 2) the data used in different studies. To obtain statistically reliable results, a large size of longitudinal data

for a large number of firms is required. However, it is difficult to obtain such a set of large longitudinal data. For construction, such data are even more limited. Many empirical studies have such limitations.

Competition and other characteristics of the construction industry were reviewed. The industry is characterized by various unfavorable terms: fragmentation, high exit rate, bankruptcy, high dependency on general economic condition, high risks, high level of competition, low innovation by contractors, etc. Risk management and competition are in the center of these characteristics of the industry. In this fragmented, risky, and highly competitive business environment, one could see potential improvements and large opportunities by making risk management and competition strategy more efficient.

Regarding contractors' business failure, most of the previous failure studies have paid attention to surface-level problems that are observable externally. A recent study by Rice and Heimbach (2007) provides new and different views on the causes of contractors' business failure: organizational issues were identified as critical underlying factors. Organizational behaviors and business patterns are affected by their own culture. Especially, risk attitude will play a critical role when contractors make risky choice facing uncertain environment. Their risk attitude as the basis of their risk perception and corresponding decisions could have critical effects on their performance: success vs. failure.

CHAPTER IV

ANALYSES OF CONSTRUCTION INDUSTRY DATA

It is difficult to measure individual contractors' risk attitudes and it is more different to evaluate the combined effects of different risk attitudes among multiple individuals in competition. Also, there are few available data for such an analysis. When selection drives evolution through the competition in a market, the effects of competition are expected to evolve in some forms at the aggregate level. Then, the effects of risk attitude on competition can be identified by analyzing the aggregate patterns. These facts lead to the need to infer risk attitudes from aggregate industry data that are available with respect to competition.

The current chapter performs analyses of the construction industry data to identify the aggregate patterns that are the resultants of competition among contractors. In construction, most of the available data are cross-sectional, and longitudinal data are limited. Construction industry data used in the analyses include:

- *U.S. Top 400 Contractors* by Engineering News-Record (from 1995 to 2007)
- *2002 Economic Census* by the U.S. Census Bureau
- *Statistics of U.S. Business (SUSB)* by the U.S. Census Bureau
 - *Dynamic Data* (from 1995 to 2004)
 - *Static Data* (from 1997 to 2005)

The phenomena or aggregate effects of interest are the size distribution of firms, organizational capacity changes by birth, death, expansion, and contraction, and market diversification. Size distributions of construction contractors are computed using the ENR data and the 2002 Economic Census data, separately. Organizational capacity changes are computed using the SUSB data which comprise annual data consisting of dynamic data and static data. And, contractors' diversification patterns are identified using the ENR data. The following sections provide descriptions about each of the industry data sets and the empirical findings through the analyses performed using the data.

4.1 Size Distribution - ENR US Top 400 Contractors

The size distribution of firms has been studied in economics since it provides a view on market structure (sometimes called market form): how much market share is obtained by various firms. Market structure describes the state of a market with respect to competition in the market. The construction industry is not concentrated but highly fragmented, as discussed in Section 3.3.1.

4.1.1 Size Distribution of ENR Contractors

Engineering News-Record (ENR, 2008) publishes summary data about the U.S. top 400 contractors every year. It has been 50 years since 1958 when ENR first ranked

construction contractors. In the first list of 1958, there were only sixty two contractors ranked based on their 1956 domestic new contract awards. At that time, the firm rankings were based on the data for contractors' domestic new contract awards published in *Construction Daily* (ENR, 2008).

Tabulations of top contractors' data that are self-reported have been improved over years. The recent data provide firms' rankings by total gross revenue, the ranked firms' international revenues, new contract awards, and previous year rank. The data also classify the construction industry into different sectors and provide the ranked firms' percent of total revenues in each sector.

The current format of the data tabulation has been used since 1995. Before 1995, firms were ranked based on new contract volume and there were no revenue data for each sector. Each annual publication of the ENR U.S. top 400 contractors is based on the previous-year data of the contractors, i.e., firm ranks and revenues data published in year 2008 are based on their business operations in year 2007.

The current analysis uses only the data set in which contractors are ranked based on their gross revenues since firm ranks based on new contract volumes are often inconsistent as a measure of firm size: sometimes, firms obtain large projects that will be performed over several years and then with a large backlog to work off they do not obtain many jobs during the next several years. As a result, available data for the current analysis cover 14 years from 1994 (published in May 1995) to 2007 (published in May 2008).

Currently, the ENR data classify the industry into eight sectors: 1) general building; 2) manufacturing; 3) power; 4) water supply and sewerage/solid waste; 5) industrial process and petroleum; 6) transportation; 7) hazardous waste; and 8) telecommunications. Descriptions of these classified sectors are in Appendix 1. The last sector, telecommunications, has appeared in the data only since the year 2000. The industry had been classified into seven sectors before year 2000. The change is due to the significant increase of construction work in the telecommunications market.

In the data, each ranked firm reports its total gross revenues and revenue percentages in each sector. There are cases that revenue percentages in different sectors do not add up to 100% due to the other miscellaneous market category. However, it was found that over the last 14 years, on average, 98.2% of the total revenues of the 400 firms are accounted in the data.

Using these ENR data, the size distribution of the contractors can be measured by their gross revenues. Figure 4.1 shows the size distribution of the ENR 400 contractors on a logarithmic scale (log-log plot), which is the common method that biologists and market ecologists apply in many competition studies as discussed in Chapter II. The size distribution of organizations has been considered as a resultant aggregate pattern evolving through competition in a population.

In Figure 4.1, the R-squared value of the trend line of 14 years average is very high, about 0.94, which is considered very good for data of this kind. Note that the contractors in the list change every year depending on their annual gross revenues.

Therefore, the samples (the contractors) vary over years while the total number of samples is constant at 400.

Contractors with various sizes measured by their gross revenues have different frequencies. The largest contractors that have gross revenues greater than \$3,000M (about 8.0 in the logarithm) have very small frequencies, i.e., 1, 2, or 3 (zero, 0.7, or 1.1 in the logarithm). The 14-year average line shows negative values of the natural log of the number of firms. It is because the small frequencies of the largest firms were averaged for the 14 years. Note that the natural log of value x is negative when $0 < x < 1$. Refer to Appendix 2 for a better view of the size distribution for each year.

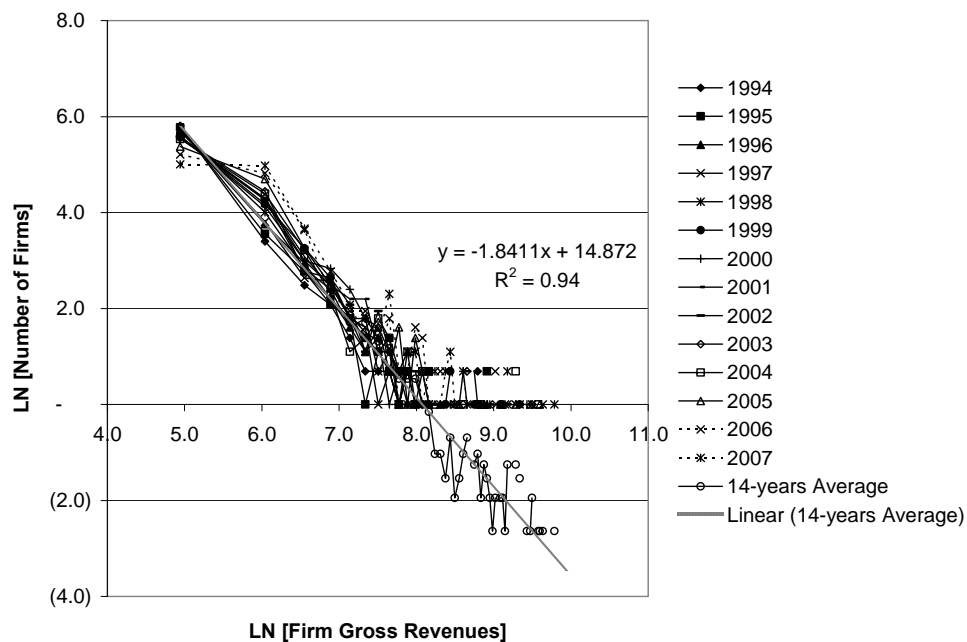


Figure 4.1 Size Distribution of ENR U.S. Top 400 Contractors

The largest contractors have high percentages of their total revenues from international projects while showing very small frequencies over 14 years. Their sparse patterns can be removed to construct the size distribution of firms to represent the competition among the remaining firms. Figure 4.2 shows the size distribution of firms without the largest firms that make negative logarithm values in the 14 years average trend line in Figure 4.2. Without the largest firms, R-squared is improved to 0.986 and the regression coefficients are essentially unchanged. On an annual average over the 14 years, 394 firms (98.5% of the total 400 firms) in the data are accounted for in Figure 4.2.

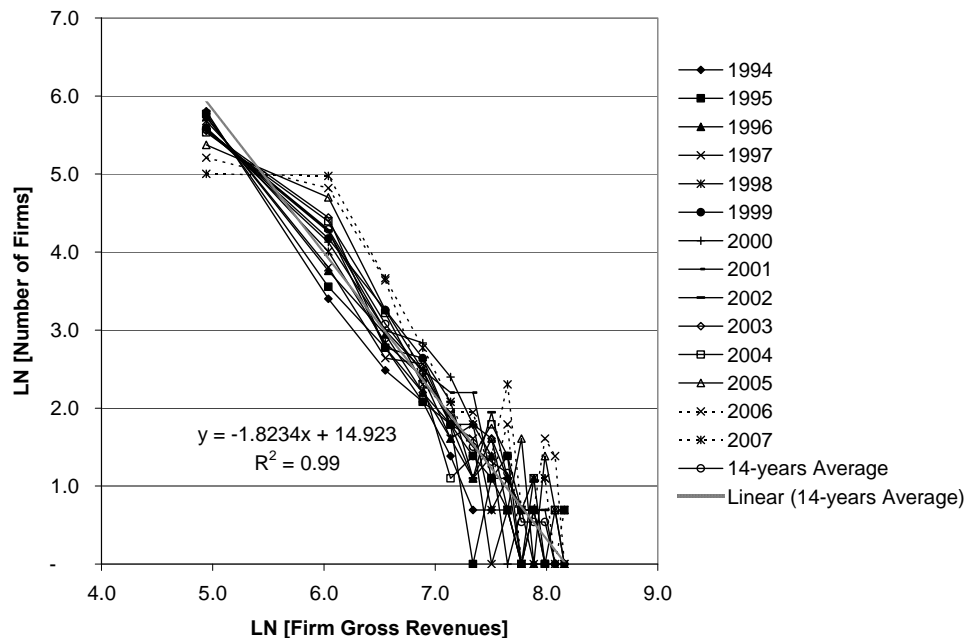


Figure 4.2 Size Distribution of ENR Contractors w/o the Largest Firms

The high values of R^2 in Figures 4.1 and 4.2 confirm the presence of the power law in construction. This empirical finding links competition in construction to

competition studies in ecology or biology: the power law governs the population of construction contractors and this would be the aggregate pattern that evolves through the contractors' (organizations') competition for common job opportunities (resources) available in the market (environment).

4.1.2 Normalization of the ENR Data

Figures 4.1 and 4.2 use fixed intervals to construct the size distributions. So, there are multiple values corresponding to one value on the x axis. Also, there are deviations from the average line. Following is the additional analysis performed to investigate the causes of the deviations. Based on the analyses, it was found that the deviations are due to the increases in the total industry gross revenues over the years.

Increasing Pattern in the Total Gross Revenues

The total sum of gross revenues of the ENR top 400 contractors has been increasing and these increases match with the historical changes in *Value of Construction Put in Place* published by the U.S. Census Bureau as shown in Figure 4.3. The two different measures (total revenues of the ENR contractors and total value of construction) were normalized for an easy comparison by setting their initial values in 1994 at 1.0. The ratios of ENR total revenues to the U.S. total revenues have been relatively stable and the average is about 0.227 (22.7%). Note that Figure 4.3 has two y-axes. It is reasonable to assume that the increases in the ENR contractors' overall

revenues relate to the overall increases in market demand assuming that inflation affects them equally.

In a close look at the ENR data, it is found that the range of gross revenues by the 400 ranked firms varies with the overall increase of total industry gross revenues. Figure 4.4 shows historical changes in the maximum gross revenues (of the 1st ranked firm) and the minimum gross revenues (of the 400th ranked firm) on the ENR lists over the 14 years. Both the maximum revenues and the minimum revenues increased. The increases of the maximum revenues have been more significant. So, the range made by the maximum and the minimum revenues has widened over the years. Note that Figure 4.4 also has two different y-axes for the maximum revenues and the minimum revenues.

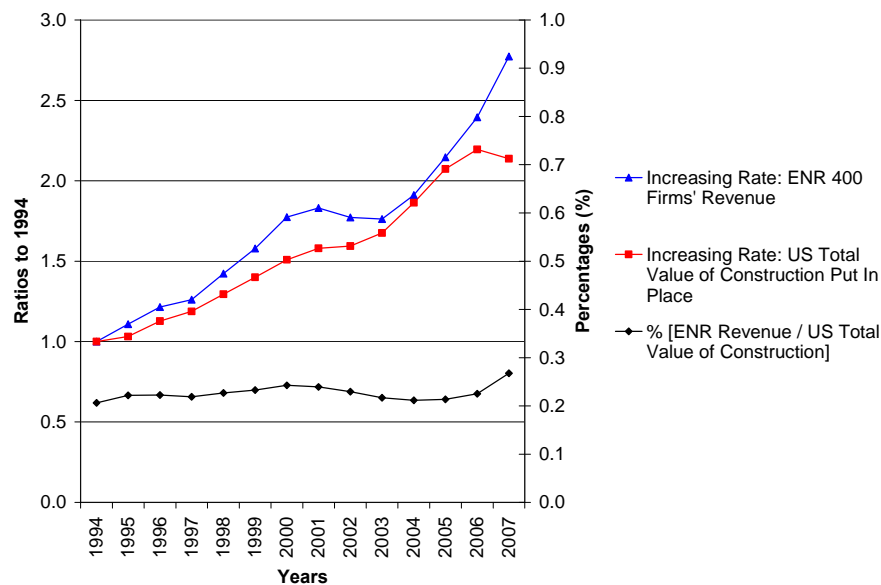


Figure 4.3 ENR Revenues vs. US Total Revenues

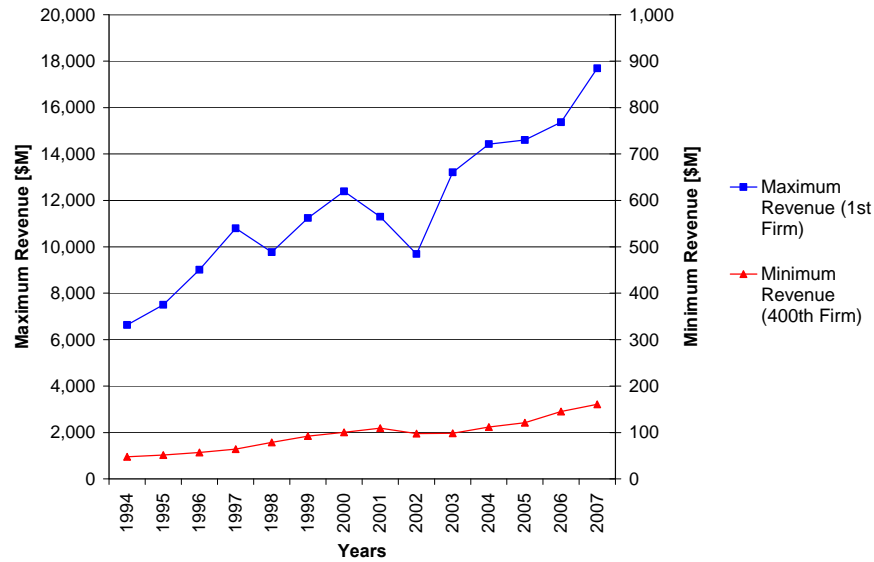


Figure 4.4 Increases in Gross Revenues on the ENR List

Varying Intervals for Different Years

The ranges from the minimum to the maximum revenues have widened over the years. In order to resolve these differences, varying intervals can be used to measure the firm frequency in different years. The varying intervals are determined by Equation 4.1.

$$I_i = \frac{(Max R_i - Min R_i)}{N} \quad [4.1]$$

Where, I_i = the size of interval for year i

$Max R_i$ = the gross revenues of the 1st ranked firm in year i

$Min R_i$ = the gross revenues of the 400th ranked firm in year i

N = the number of size intervals (50, same for all 14 years)

Figure 4.5 shows the size distributions of the ENR top 400 contractors over the 14 years based on firm frequencies measured using varying intervals. Now, the distributions have different x ordinates for each year. The effects of the increases in the overall revenues are apparent in Figure 4.5: the movements of distributions toward the right hand side (larger gross revenues) over the years. This pattern was not identifiable in Figure 4.2 using fixed intervals. However, the linear patterns in these distributions are still similar between different years. Table 4.1 provides the slopes, intercepts, and values of R-squared of the linear trend lines found in size distributions shown in Figure 4.5. For the 14 years, the average slope is about -1.83, the average intercept is about 14.9, and the average R-squared is about 0.94, using the varying intervals.

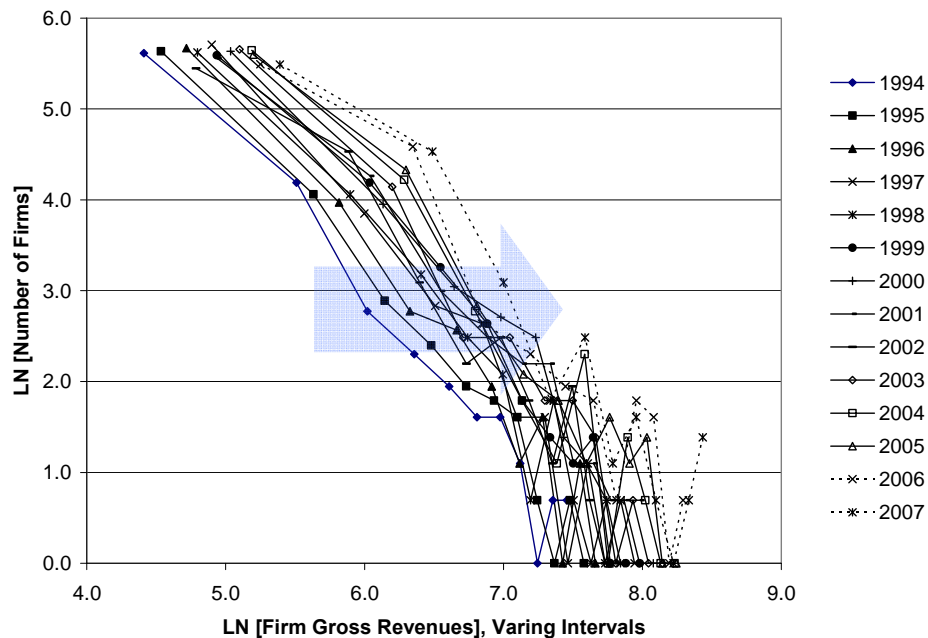


Figure 4.5 Size Distribution of the ENR Contractors Using Varying Intervals

Table 4.1 Slopes and Values of R-squared of the Linear Trend Lines

Year	Slope	Intercept	R-squared
1994	-1.75	13.48	0.96
1995	-1.85	14.26	0.97
1996	-1.89	14.78	0.95
1997	-1.91	15.20	0.94
1998	-1.89	15.00	0.94
1999	-1.94	15.62	0.96
2000	-1.89	15.52	0.97
2001	-1.71	14.25	0.98
2002	-1.81	14.61	0.92
2003	-1.91	15.64	0.96
2004	-1.88	15.58	0.90
2005	-1.81	15.21	0.95
2006	-1.69	14.57	0.90
2007	-1.77	15.32	0.89
Average	-1.83	14.93	0.94

In order to check the statistical stability of the slopes and intercepts over multiple years, control charts were constructed as shown in Figures 4.6 and 4.7 using the data in Table 4.1. The control charts were constructed with natural process limits calculated based on *mean range* since there is only one observation for each time period. The natural process limits are defined by the mean plus and minus three standard deviations (for six-sigma limits). As found in Figures 4.6 and 4.7, there is no specific pattern in the control charts. It can be concluded that the slopes and the intercepts are under statistical control and these variations in the size distribution of the ENR 400 contractors are random.

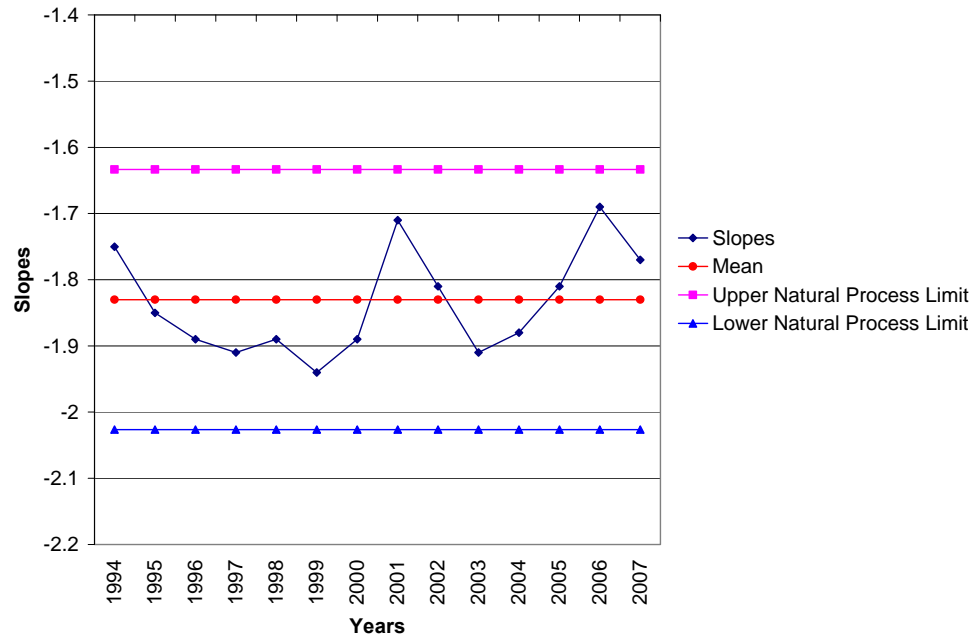


Figure 4.6 Control Chart for Slopes

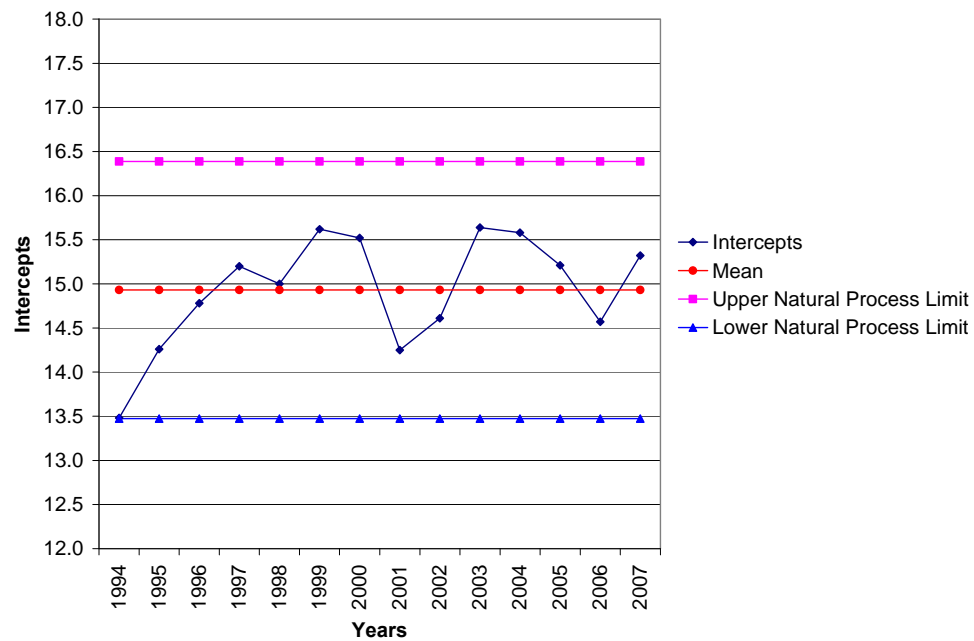


Figure 4.7 Control Chart for Intercepts

Application of the Mean Intervals

The analysis takes an additional step to confirm the similarity among the size distributions over the 14 years. Figure 4.8 shows the size distributions of the ENR top 400 contractors using the mean of the varying intervals. The mean is the 14 years average of the varying intervals. Using the mean intervals, the distributions have multiple y values for one x ordinate. The size distributions become more stable and more similar by reducing the size of deviations caused by the increasing pattern in the firm gross revenues in the data, resulting in a high R^2 value, 0.98. The distributions in Figure 4.8 confirm again the presence of the power law in the population of large contractors. The line's slope and intercept are -1.836 and 15.05, respectively. Refer to Appendix 2 for a better view of the size distribution in each year.

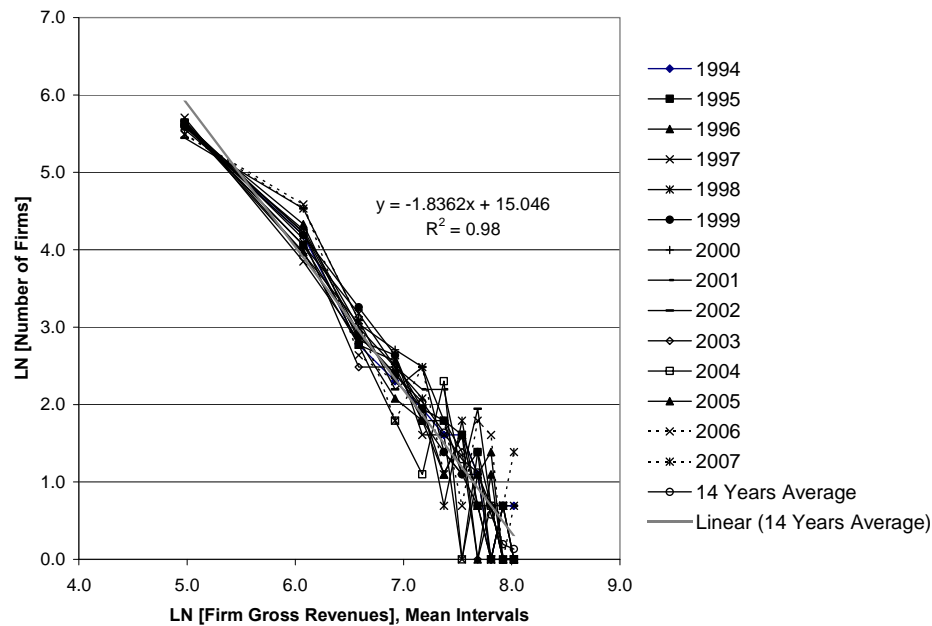


Figure 4.8 Size Distribution Using the Mean Intervals

4.1.3 *International Revenues vs. Domestic Revenues*

Internationalization in the construction business has been a common phenomenon for large contractors in the U.S. over recent decades. Table 4.2 provides an analysis of the international and domestic revenues by the ENR contractors. The number of the international revenue firms has been stable among the 400 firms. On average, about 80 contractors obtained some of their revenues from international projects each year.

As shown in Table 4.2, the percentages of international revenues and domestic revenues by the ENR 400 contractors have been stable. But, the total volume of international revenues has increased. In year 1994, the total sum of international revenues was \$16,519 million ($\$ 109,735.3 \times 15.1\%$). In year 2007, the total sum of international revenues was \$47,499 million ($\$ 304,360.9 \times 15.6\%$), which is 2.9 times the 1994 international revenues. More than 90% of the total international revenues have been earned by the largest firms that have been ranked between 1st and 50th as shown on the most right hand side column in Table 4.2. However, the percentages have decreased slightly over the years from about 95% to 91%.

Among the ENR 400 contractors, large firms (mostly, highly-ranked firms) have international revenues and small firms (mostly, low-ranked firms) have small or no international revenues. Then, it can be questioned whether the size distribution of firms would change when only the domestic revenue firms are considered for the distribution since the international revenue firms might have different types of competition in

international markets, for example, from large international contractors based in other countries rather than smaller domestic contractors.

Table 4.2 Analysis on International Revenues by the ENR Contractors

Year	Total Gross Revenues	International Revenues	Domestic Revenues	Number of Firms having Intl. Revenues	% of the Total Intl. Revenues by the highly-ranked firms (1 - 50)
1994	\$ 109,735.3	15.1%	84.9%	80	94.6%
1995	\$ 121,648.8	16.4%	83.6%	79	95.6%
1996	\$ 133,350.4	17.8%	82.2%	72	94.1%
1997	\$ 138,344.3	18.4%	81.6%	77	92.3%
1998	\$ 156,130.9	18.2%	81.8%	82	91.4%
1999	\$ 173,292.1	17.1%	82.9%	88	92.7%
2000	\$ 194,637.3	13.1%	86.9%	83	92.7%
2001	\$ 201,002.1	11.0%	89.0%	81	90.8%
2002	\$ 194,390.2	10.1%	89.9%	80	92.4%
2003	\$ 193,352.9	13.9%	86.1%	75	92.8%
2004	\$ 209,737.0	15.6%	84.4%	79	91.3%
2005	\$ 235,562.7	15.1%	84.9%	78	90.2%
2006	\$ 262,759.6	15.0%	85.0%	80	91.2%
2007	\$ 304,360.9	15.6%	84.4%	75	91.6%

To resolve the possible difference, the size distributions of domestic revenue firms were constructed. The same method was applied to measure firm frequencies using the varying intervals and the mean intervals (the means of the varying intervals), shown in Figure 4.9 and Figure 4.10, respectively. Again, Figure 4.9 shows the effects

of the increased total revenues of the ENR 400 contractors over the 14 years. Refer to Appendix 2 for a better view of the size distribution for each year in Figure 4.10.

From Figures 4.8 and 4.10, there are no significant differences between domestic competition and international competition. No significant changes were found in the size distributions of firms regardless of whether the data include all 400 firms or only domestic revenue firms.

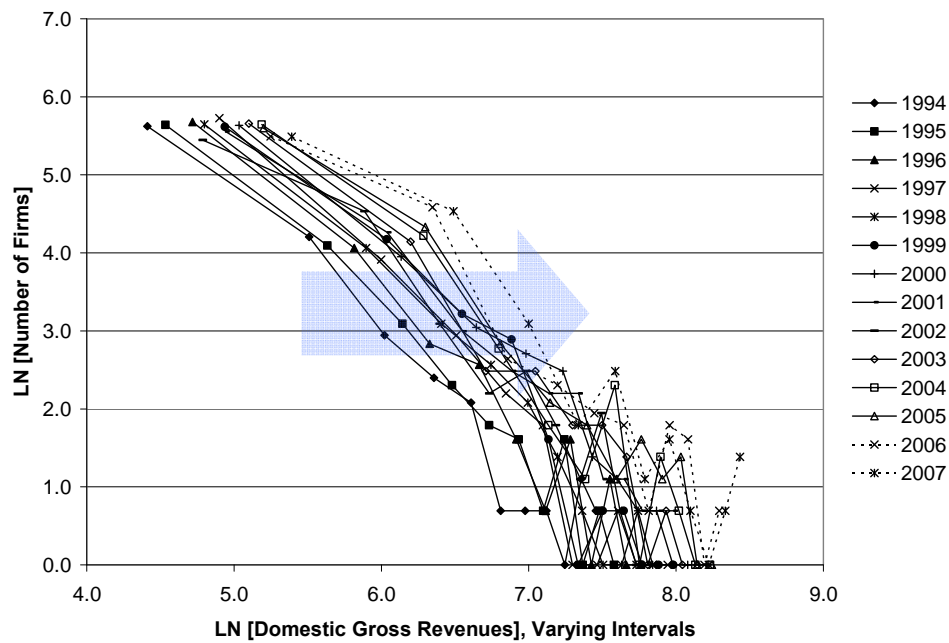


Figure 4.9 Size Distribution of ENR Domestic Firms Using Varying Intervals

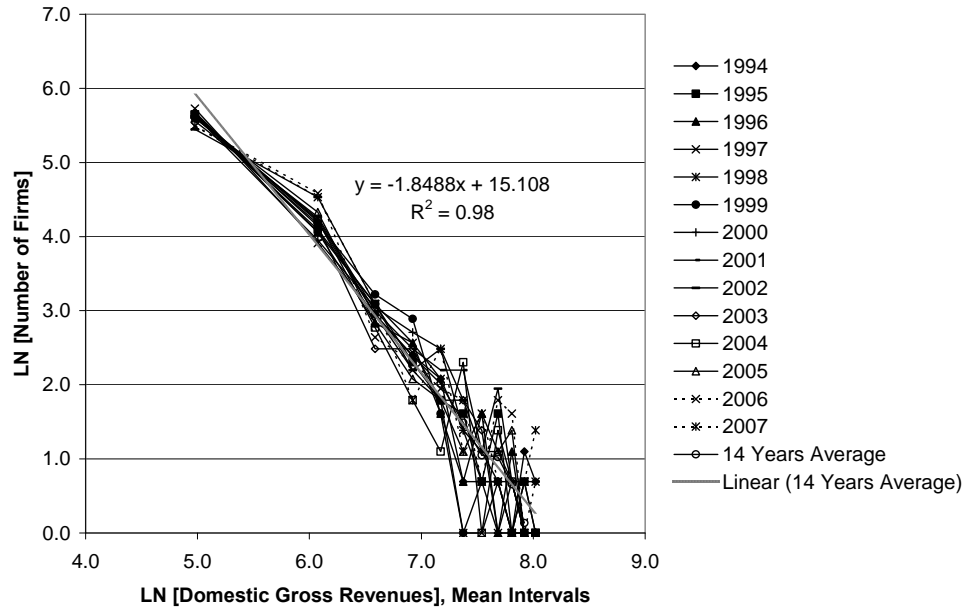


Figure 4.10 Size Distribution of ENR Domestic Firms Using Mean Intervals

Table 4.3 below provides a comparison of the two size distributions between using all 400 firms and using only domestic revenue firms. The values of their slopes, intercepts, and R-squared are similar to each other. There is no apparent difference between the two size distributions. Therefore, they are drawn from the same population. So, domestic firms are not significantly different from all firms and firms that work internationally are not different from those that don't.

Table 4.3 Comparison of 14 years Average Trend lines

Size Distribution	Slope	Intercept	R^2
Total 400 Firms (Figure 4.8)	-1.8362	15.046	0.985
Domestic Revenue Firms (Figure 4.10)	-1.8488	15.108	0.985

4.2 Size Distribution - 2002 Economic Census

The Economic Census data also can be used to construct the size distribution of business organizations. The 2002 Economic Census is another source of construction industry data. These data are published by the U.S. Census Bureau every five years. The 2002 Economic Census provides information about business organizations at the establishment level for all U.S. industries classified based on NAICS (North American Industry Classification System). In the data set for each industry, business organizations are classified at the establishment level by the number of employees, the location, and the business volume done. The data also provide additional information such as the amount of payroll, specialization level, industry statistics, etc.

4.2.1 *Size Distribution of Establishments in Construction*

While the ENR data provide information about large construction firms that are ranked 1st to 400th based on firm gross revenues, the 2002 Economic Census data count business organizations at the establishment level and the size of an establishment is measured by its employment size, i.e., the number of employees. An establishment is defined as a single physical location where business is performed. A firm can have more than one establishment. Multiple establishments controlled by one firm may locate in more than one market sector.

In construction, firms that have multiple establishments are usually large in size. According to an analysis using the *Statistics of US Business* which will be discussed in a later section in detail, during the 9 years from 1997 to 2005, the average number of

establishments per construction firm was 1.01. Meanwhile, for large construction firms that have more than 500 employees, the average number of establishments per firm is 6.94.

Table 4.4 shows the classification of the construction industry by 2002 NAICS, the construction industry is classified largely into three major sectors: 1) building construction; 2) heavy and civil engineering construction; and 3) specialty trade contractors. Refer to the website of the U.S. Census Bureau for details on sub-classifications.

Table 4.4 2002 NAICS Classification for the Construction Industry

NAICS
23 Construction
236 Construction of Buildings <ul style="list-style-type: none"> 2361 Residential Building Construction <ul style="list-style-type: none"> 236115 New Single-Family Housing Construction 236116 New Multifamily Housing Construction 236117 New Housing Operative Builders 236118 Residential Remodelers 2362 Nonresidential Building Construction <ul style="list-style-type: none"> 23621 Industrial Building Construction 23622 Commercial and Institutional Building Construction
237 Heavy and Civil Engineering Construction <ul style="list-style-type: none"> 2371 Utility System Construction <ul style="list-style-type: none"> 23711 Water and Sewer Line and Related Structures Construction 23712 Oil and Gas Pipeline and Related Structures Construction 23713 Power and Communication Line and Related Structures Construction 2372 Land Subdivision 2373 Highway, Street, and Bridge Construction 2379 Other Heavy and Civil Engineering Construction
238 Specialty Trade Contractors <ul style="list-style-type: none"> 2381 Building foundation and exterior contractors 2382 Building equipment contractors 2383 Building finishing contractors 2389 Other specialty trade contractors

Using 2002 Economic Census data, size distributions of establishments for construction can be constructed for the total industry, as well as each of three major sectors classified in Table 4.4. Figure 4.11 shows the four different size distributions of establishments (measured by the employment size). Power laws are observed again in the log-log plots for total general contractors and each group of general building contractors, heavy contractors, and specialty trade contractors. The linear trend lines have negative values for the slopes and positive values for the intercepts. Also, they all have very high R-squared values.

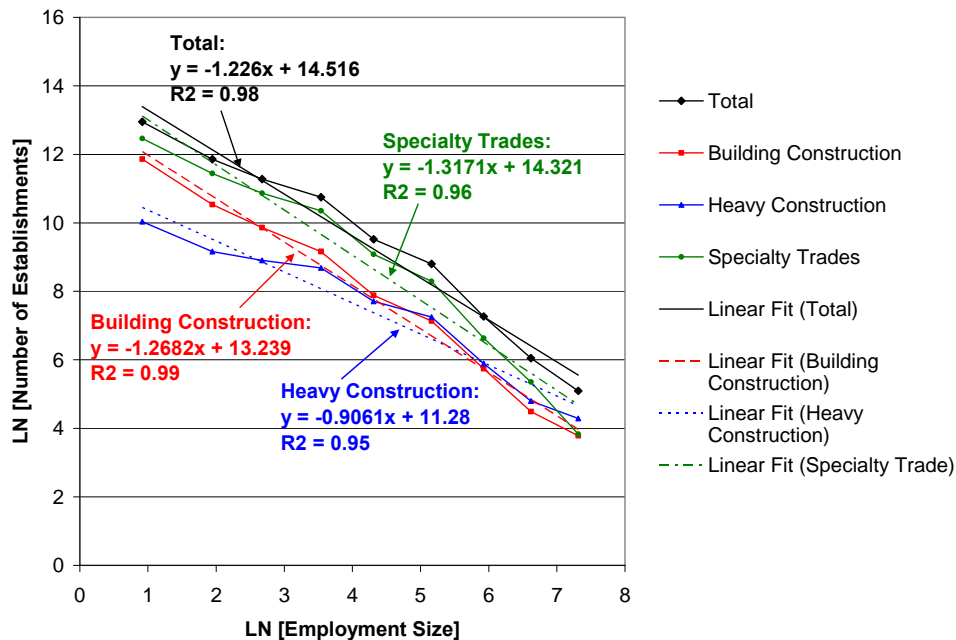


Figure 4.11 Size Distribution of Establishments in Construction

The slopes of linear trend lines in Figure 4.11 are lower than the slope found using the ENR top 400 Contractors data, which is -1.836 as shown in Figure 4.8. These

differences between the ENR data and the Economic Census data would be due to the differences in the size measurement of organizations and the level of data. The ENR U.S. top 400 Contractors data take into account firms and the size of a firm as measured by firm gross revenues in U.S. dollars. Also, the firms in the ENR data are all large firms in the U.S. construction industry (having more than 500 employees). On the other hand, the 2002 Economic Census data count establishments and the size of an establishment is measured by the number of employees. And, the data include establishments of all sizes.

However, the size distributions using two different industry data sets have one common characteristic, which is linearity with negative slopes. Moreover, using the 2002 Economic Census data, a similar slope (to the slope using the ENR data) is found when only large establishments (more than 100 employees) are used to construct the size distribution, which is shown in Figure 4.12.

Table 4.5 provides a comparison of the size distributions using different construction industry data, for different market sectors and different size groups. There are small differences in slopes. The differences might be due to some specific characteristics between sectors. Different characteristics could be found in the level of risk in jobs and competition, different overhead expenditures or capital needs, higher or lower entry barrier, level of equipment uses, etc. The identified differences in the size distribution among different market sectors are left for future investigation.

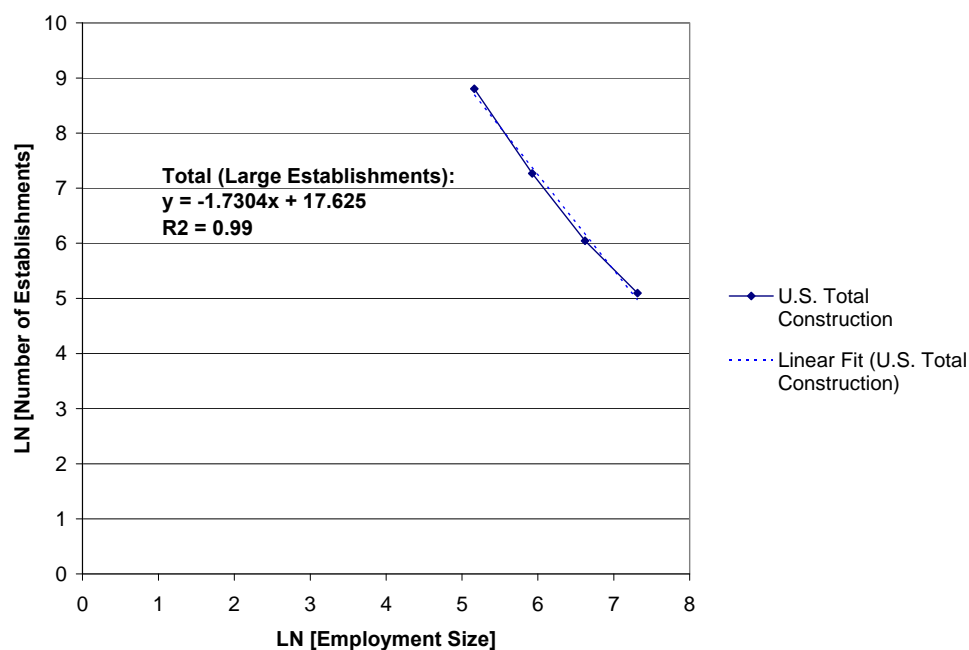


Figure 4.12 Size Distribution of Large Establishments in Construction

Table 4.5 Comparison of Size Distributions for Different Market Sectors

Data	Population in the Data	Slope	Intercept	R ²
ENR top 400 Contractors	Large firms	-1.836	15.05	0.985
2002 Economic Census	Total establishments in construction	-1.226	14.52	0.976
	Establishments in building construction	-1.268	13.24	0.990
	Establishments in heavy and civil construction	-0.906	11.28	0.952
	Establishments in specialty trades	-1.317	14.32	0.962
	Only large establishments	-1.730	17.63	0.993

4.2.2 *Size Distribution of Establishments in Other Industries*

Different shapes for the size distribution are found in other industries. The 2002 Economic Census also provides other industries data. For the purpose of comparison, establishment data on the total manufacturing industry and the paper manufacturing industry were analyzed. Figures 4.13 and 4.14 provide the size distributions of establishments in these industries.

The two distributions are different from the construction industry. For the total manufacturing industry in Figure 4.13, the data (frequency of firms) are deficient at the small firm level compared to the linear fit. That is, large firms have driven small firms out of business, but this is not true in construction. Meanwhile, in Figure 4.14, a significant curvature is found for firms in paper manufacturing, which is a capital-intensive industry. In general, paper manufacturers utilize large automated machines that are expensive and they need little labor to manage the machines. So, the number of establishments with small employment sizes is less than the power law would predict.

The differences in the size distributions of firms in different industries, especially the slopes, might be due to differences in the characteristics of their businesses. As discussed earlier, the differences would be found in the level of capital needs (labor-intensive or capital-intensive), overhead, different market risks, etc. And, due to these differences in business environment, organizations in an industry could compete with each other in different ways. It will be an interesting topic for future investigation. The current study leaves it behind to focus on the investigation of competition in the construction industry.

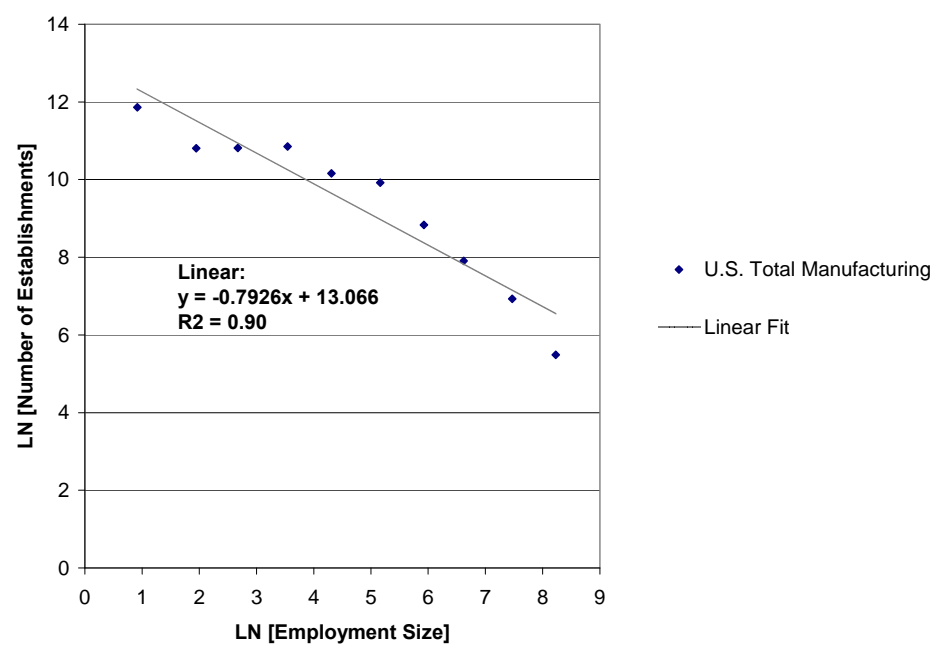


Figure 4.13 Size Distribution in the Manufacturing Industry

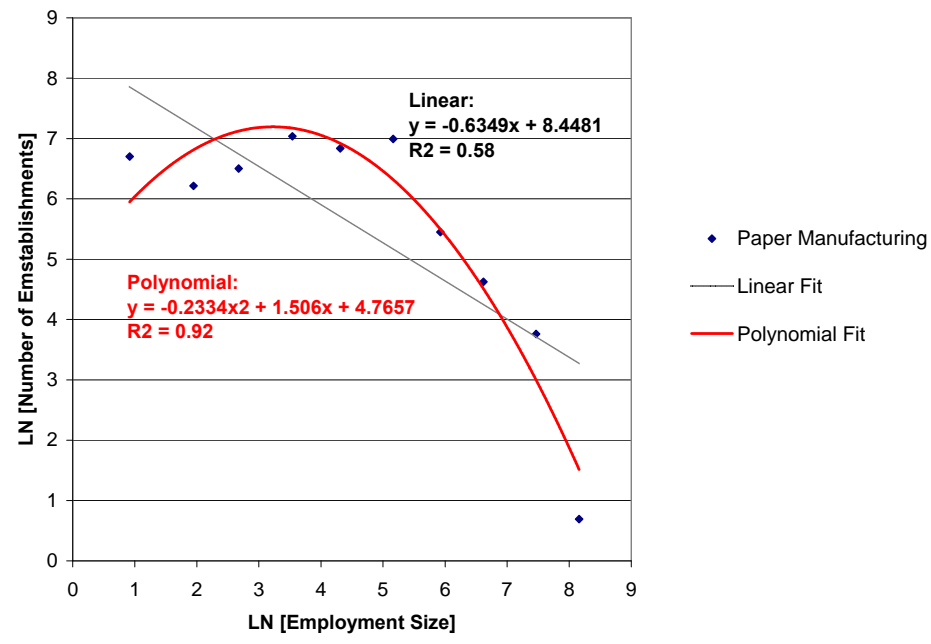


Figure 4.14 Size Distribution in the Paper Manufacturing Industry

4.3 Interpretation of Power Law in the Size Distribution

There have been many empirical findings regarding the power law in different systems: biology, ecology, and industry organization studies. However, there are few explanations about what underlies the power law. This section provides an interpretation of the power law found in the size distribution of construction firms.

Define elasticity in general as the percentage change in one variable for a given percentage change in another. Also, define construction firm elasticity as the percentage change in the number of firms (N) for a given change in firm revenues (R). Hence, the elasticity can be expressed as in Equation 4.2.

$$Elasticity = \frac{dN}{N} \frac{R}{dR} = \frac{dN}{dR} \frac{R}{N} \quad [4.2]$$

As found in Equation 2.4 in Chapter II, a power law relation can be defined as

$N = \alpha R^\beta$ or $\text{Log}N = \alpha + \beta \text{Log}R$. Then,

$$\begin{aligned} N &= \alpha R^\beta \\ \frac{dN}{dR} &= \alpha \beta R^{\beta-1} \\ Elasticity &= \frac{dN}{dR} \frac{R}{N} = \alpha \beta R^{\beta-1} \frac{R}{\alpha R^\beta} = \beta < 0 \end{aligned} \quad [4.3]$$

Therefore, the power law relation gives a constant elasticity. Figure 4.15 provides a graphical representation of the power law relation: elasticity governs the

percentage changes in the number of firms (ΔN) and the firm revenue (ΔR). If the revenue per firm is decreased by 1%, the number of firms increases by $|\beta|\%$. This is perhaps the reason behind the ubiquity of power law relations shown by biological, ecological, and organizational data. The construction value of elasticity indicates that the tradeoff between firm size (revenue) and number of firms that size is independent of firm size.

Conversely, for some manufacturing sectors as shown Figures 4.13 and 4.14, the elasticity varies. There can be a range of zero elasticity at which the number of firms is inelastic to changes in firm size and even a region of positive elasticity, in which there are few smaller firms (possibly a threshold effect). But, in construction, constant elasticity implies that, if a firm can raise its revenues by 1%, it will encounter $|\beta|\%$ fewer competitors, for all sizes of firms. With a computed value of $\beta \cong -1.84$ as found in Figure 4.8, number of construction firms is much more sensitive to revenue (size) changes than manufacturing firms with $\beta \cong -0.79$ as found in Figure 4.13.

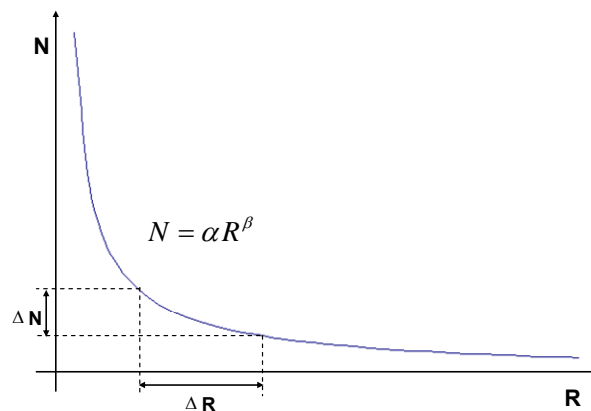


Figure 4.15 Elasticity by the Power Law

4.4 Organizational Changes in Employment

The U.S. Census Bureau publishes *Statistics of U.S. Business* (SUSB) annually in cooperation with the Office of Advocacy of the U.S. Small Business Administration (SBA) (<http://www.census.gov/>). The SUSB provides macro economic data on the U.S. economy. The tabulations started in 1989. There are two types of data sets in the Statistics of U.S. Business: dynamic data and static data.

- Dynamic data: the data provide dynamic information about employment changes in business organizations: the number of establishments and changes in employment size (the number of employees) by births, deaths, expansions, and contractions at the establishment level.
- Static data: the data provide static information about the state of industries measured at a certain time of each year (in the mid-March pay period). The data tabulate the number of firms, establishments, employments, and annual payroll by the enterprise employment size.

For both data sets, the employment size is determined by the number of employees (full and part-term employees, including salaried officers and executives of corporations) who were on the payroll in the pay period including March 12.

There exist comparability problems in the data due to the changes in industry definitions and classifications. The most recent changes in the industry classification for construction were made in 1998. Before 1998, the construction industry had code number *SIC15* based on Standard Industrial Classification (SIC). Currently, the code number is *NAICS23* based on North American Industry Classification System (NAICS).

In 2002, there were small modifications in NAICS, but the code number and classification for the construction industry has maintained the same structure since 1998. The industry classification based on the 2002 NAICS is shown in Table 4.4. Since the current study analyzes the data sets at the total industry level, the comparability problems are avoided.

For use in the current study, the available dynamic data cover 1995 to 2004 and the available static data cover 1997 to 2005. These data are available from the official website of the U.S. Census Bureau (<http://www.census.gov/>). The SUSB classifies establishments and firms by enterprise employment size and define establishment, firm, and enterprise as follows:

- An establishment: a single physical location at which business is conducted or where services or industrial operations are performed.
- A firm: a part of an enterprise tabulated within a particular industry, state or metropolitan area. A firm can have multiple establishments.
- An enterprise: a business organization consisting of one or more domestic establishments under common ownership or control. An enterprise can have multiple firms in different states.

In the SUSB, the enterprise, the firm, and the establishment are the same organization if an enterprise has one establishment. An enterprise with establishments in more than one state is counted as a firm in each state where it operates an establishment. But, the enterprise is counted as only one firm in national all-industry tabulations. Therefore, an enterprise is identical to a firm in national all-industry tabulations, but they

are not identical in state tabulations. The size of a firm or an enterprise is determined by the total sum of employment in all associated establishments. For the current study, all analyses are performed using national all-industry tabulations so that a firm and an enterprise are identical.

4.4.1 Dynamic Data of the SUSB

The dynamic data provide the number of establishments and employment changes at the establishment level. The general rule used in the data tabulation is that the state of an establishment is determined by the initial year data for establishment deaths and continuing establishments and by the subsequent year data for establishment births. Organizational changes at the establishment level are defined as below (<http://www.census.gov>):

- Births: establishments that have zero employment in the first quarter of the initial year and positive employment in the first quarter of the subsequent year.
- Deaths: establishments that have positive employment in the first quarter of the initial year and zero employment in the first quarter of the subsequent year.
- Expansions: establishments that have positive first quarter employment in both the initial and subsequent years and increased employment during the time period between the first quarter of the initial year and the first quarter of the subsequent year.
- Contractions: establishments that have positive first quarter employment in both the initial and subsequent years and decreased employment during the time

period between the first quarter of the initial year and the first quarter of the subsequent year.

The following analysis using the dynamic data reveals that employment changes by expansions and contractions are very significant. Table 4.6 shows the frequencies

$$\left(= \frac{\text{Number of Establishments with Certain Type of Change}}{\text{Total Number of Establishments}} \right) \text{ and the amounts of}$$

employment changes by births, deaths, expansions, and contractions at the establishment level for the construction industry. Table 4.7 provides the same type of information for the U.S. total industry. The tabulated data include all establishments in these industries.

Table 4.6 Employment Changes in the Construction Industry

	Frequency of Changes				% Changes in Employment Size			
	Births	Deaths	Expansions	Contractions	Births	Deaths	Expansions	Contractions
1995-1996	15.2%	13.0%	30.9%	27.8%	6.7%	6.1%	16.9%	14.4%
1996-1997	15.0%	12.5%	32.7%	26.2%	6.8%	6.4%	18.5%	13.2%
1997-1998	14.1%	12.9%	30.7%	27.4%	6.4%	6.3%	16.9%	13.3%
1998-1999	14.1%	12.1%	33.0%	25.1%	6.6%	6.1%	18.4%	11.7%
1999-2000	13.5%	12.0%	32.7%	25.7%	6.1%	5.8%	18.2%	12.0%
2000-2001	12.5%	12.4%	28.6%	28.6%	5.5%	6.0%	14.9%	13.3%
2001-2002	13.4%	13.7%	28.7%	28.1%	6.7%	6.6%	13.3%	16.0%
2002-2003	14.8%	13.2%	29.0%	28.1%	6.4%	6.0%	14.5%	14.9%
2003-2004	16.3%	12.7%	31.9%	25.4%	6.4%	6.2%	16.7%	12.7%
2004-2005	16.2%	13.0%	29.6%	27.4%	7.0%	5.9%	15.0%	14.2%
10 years Average	14.5%	12.8%	30.8%	27.0%	6.4%	6.2%	16.3%	13.6%

Table 4.7 Employment Changes in the U.S. Total Industry

	Frequency of Changes				% Changes in Employment Size			
	Births	Deaths	Expansions	Contractions	Births	Deaths	Expansions	Contractions
1995-1996	11.9%	10.3%	29.2%	26.7%	5.9%	5.0%	10.3%	9.3%
1996-1997	13.8%	11.3%	29.8%	26.3%	7.5%	5.8%	11.6%	10.2%
1997-1998	11.8%	10.7%	29.8%	25.9%	6.0%	5.4%	11.2%	9.1%
1998-1999	11.5%	10.6%	29.2%	26.0%	5.9%	5.3%	10.8%	9.1%
1999-2000	11.3%	10.6%	29.8%	25.4%	5.9%	5.4%	11.3%	8.8%
2000-2001	11.5%	10.8%	28.1%	26.9%	5.9%	5.3%	10.2%	9.9%
2001-2002	12.4%	11.8%	27.4%	28.4%	6.7%	6.1%	9.6%	12.5%
2002-2003	11.5%	10.4%	28.4%	26.6%	5.7%	5.4%	10.6%	10.0%
2003-2004	11.6%	10.2%	28.5%	25.9%	5.5%	5.2%	10.3%	9.2%
2004-2005	11.7%	10.3%	27.5%	27.1%	5.6%	4.8%	9.7%	9.4%
10 years Average	11.9%	10.7%	28.8%	26.5%	6.1%	5.4%	10.6%	9.7%

As shown in Tables 4.6 and 4.7, business organizations in construction have higher frequencies and percent changes in employment compared to those in the U.S. total industry. It can be easily found in the 10 year averages. It is well known that the construction industry has high entry and exit rates. There are few entry barriers because there are low capital requirements to enter into the construction business. Due to the high entry rates and inherent high level of business risks, the industry also has a high exit rate (Broemser, 1968).

The analysis was performed further for a group of large business organizations that have more than 500 employees since the ENR U.S. Top 400 contractors belong to this size group. The analysis finds the large construction contractors have experienced annual averages of 13.7% and 14.9% in employment changes by their expansions and

contractions, respectively. It indicates significant moves of people between construction firms. These rates are much higher than the U.S. total industry averages: 8.9% and 9.4% for the class of all large establishments. The large construction contractors' average employment changes by births and deaths are 5.4% and 4.9%, respectively, which are close to the U.S. total averages: 5.4% and 4.7%. Over the years, the rates of organizational changes have been relatively stable with small fluctuations.

4.4.2 *Static Data of the SUSB*

While the dynamic data provide meaningful information on employment changes related to organizational changes, the static data provide information about the state of the U.S. industries: how many firms and establishments exist and how many employees work for the establishments and firms. The measures are made at a certain time of each year (in the mid-March pay period) so that the measures are static.

Using these static data, the average number of establishments per firm can be measured. Table 4.8 shows the average number of establishments per firm measured over the 10 years from 1995 to 2005. For all construction firms in the industry, the average number of establishments per firm is 1.01, which is much lower than the other two averages for the U.S. total industries and the manufacturing industry. For large firms, large construction contractors have about 6.9 establishments on average, which is also smaller than the other industry averages. On average, a large manufacturing firm has 8.7 establishments and a large business firm in the U.S. has 58.83 establishments.

Table 4.8 Average Number of Establishments per Firm

Industry	All Firms	Only Large Firms (more than 500 employees)
U.S. Total Industries	1.25	58.83
Manufacturing Industry	1.16	8.65
Construction Industry	1.01	6.94

4.5 Contractors' Market Diversification

The current study pays attention to the market diversification of construction contractors. Using the static data of the SUSB, it was found that large construction contractors have about seven establishments on average. However, there is no information about market diversification in the SUSB data. A contractor may have multiple establishments in only one market sector through geographical diversification, or have multiple establishments in different market sectors as market diversification. The current study focuses on contractors' market diversification.

Even though competitive strategies are considered to be critical to construction firms, strategic management has not received much attention due to the concentration on project management and competitive bidding problems. Betts and Ofori (1992) identified several hindrances in strategic planning in construction. The hindrances include organizational fragmentation, inefficient feedback, low level of technology, and low entry barriers.

Nevertheless, market diversification is considered a major strategy for contractors' growth (Hillebrandt and Cannon, 1989). Junnonen (1998) asserted that

contractors spread their risk by diversifying in more than one business sector, preferably contra-cyclical. However, no significant performance difference was found between contractors with high and low diversification (Choi and Russell, 2005). The current literature in construction does not provide consistent recommendations about market diversification.

4.5.1 Measure of Diversification

There have been many studies on firm diversification in strategic management but there are only a few studies about construction firms' diversification. However, as discussed in Chapter III, these management studies also do not provide a consensus in their empirical tests. One of the most critical questions in the literature is about the relationships between a firm's diversification and its economic performance.

In the literature, different measures of firm diversification have been used. Most of these measures have direct counterparts in similar measures of industrial/market structure (Jacquemin and Berry, 1979). According to Jacquemin and Berry, three measures are mostly used: concentration ratio; Herfindahl index; and entropy measure. Each of them is discussed below.

Concentration Ratio

$$I = \sum_{i=1}^n p_i w_i \quad [4.4]$$

In Equation 4.4, p_i is the share of either the i^{th} firm (for industry concentration) or the i^{th} industry (for firm market diversification), w_i is an assigned weight (percentage of total revenues or production), and n is the number of firms or products.

This concentration ratio has been used in many studies because of its historical availability from the Bureau of the Census. Different measures of concentration ratio are found in the literature. Curry and George (1981) provide an extensive review on concentration ratio.

Herfindahl Index

$$HI = 1 - \sum_{i=1}^N p_i^2 \quad [4.5]$$

In Equation 4.5, p_i is revenue share of the i^{th} market segment in the firm's total revenues and N is the number of segments. If the Herfindahl index for a firm is close to 1.0, the firm is more diversified than another firm with Herfindahl index close to 0.0.

Entropy Measure

$$Entropy = \sum_{i=1}^N p_i \ln \left(\frac{1}{p_i} \right) \quad [4.6]$$

In Equation 4.6, p_i is revenue share of the i^{th} segment in the firm's total revenues. and N is the number of market segments. Entropy measure is also known as Shannon Index or Shannon Information Content to measure diversity in data (Shannon, 1948).

In addition to these three measures, there are other measures in the literature. For example, Gort (1962) defined the ratio of the firm's sales within the firm's primary industry (having the largest share) to the firm's total sales as one measure of firm diversification.

Among these available measures, the current study uses entropy measure as a firm diversity index, which is mostly favored due to its mathematical advantages: the measure is additive (it can be decomposed into additive elements that contribute to the total) and sensitive (it accounts better for low levels of diversification compared to other measures) (Jacquemin and Berry (1979); Palepu (1985)).

In Equation 4.6, the maximum value of firm diversity index using the entropy measure may vary depending on the size of N . Maximum diversity index value can be calculated assuming a uniform distribution of revenue fractions cross over all sectors. Fortunately, the maximum value is equal to $\log[N]$. Therefore, it is easy to normalize entropy measures by dividing by the logarithmic value of the total number of sectors, $\log[N]$ so that all measures are scaled onto the interval $[0.0, 1.0]$.

Table 4.9 provides an example of the entropy measure for a firm assuming there are only two market segments, A and B for simplicity. Different combinations of

revenue fractions in each segment are tested. In this example, there are only two market segments so the maximum entropy that is possible when the firm has even amounts of its revenues in each sector is $\log[N = 2]$.

For the normalization of entropy measures, all measures are divided by $\log[2] = 0.6931$. When the firm has uniform distribution of its gross revenues (50:50) in different sectors A and B, the firm's diversity index equals 1.0. In contrast, the firm's diversity index decreases as the distribution of firm's gross revenues are skewed. The firm's diversity index is zero when it has all gross revenues in only one sector A or B as shown in Table 4.9.

Table 4.9 Example of Calculation of Diversity Index – Two Sectors A & B

Different combinations of revenue fractions		$Entropy = \sum_{i=1}^N p_i \ln \left(\frac{1}{p_i} \right)$			
Sector A	Sector B	Contribution by Sector A	Contribution by Sector B	Entropy for the Firm (Sum of contributions)	Normalized Entropy
0%	100%	0.0000	0.0000	0.0000	0.0000
10%	90%	0.2303	0.0948	0.3251	0.4690
20%	80%	0.3219	0.1785	0.5004	0.7219
30%	70%	0.3612	0.2497	0.6109	0.8813
40%	60%	0.3665	0.3065	0.6730	0.9710
50%	50%	0.3466	0.3466	0.6931	1.0000
60%	40%	0.3065	0.3665	0.6730	0.9710
70%	30%	0.2497	0.3612	0.6109	0.8813
80%	20%	0.1785	0.3219	0.5004	0.7219
90%	10%	0.0948	0.2303	0.3251	0.4690
100%	0%	0.0000	0.0000	0.0000	0.0000

Figure 4.16 depicts a graphical representation of various levels of diversification for a firm, assuming different combinations of revenue fractions in Table 4.9. As

discussed, using the entropy measure is advantageous compared with other measures thanks to the mathematical advantages, i.e., to be additive and sensitive. Using other measures, it is not easy to normalize different firms' diversification level for comparison.

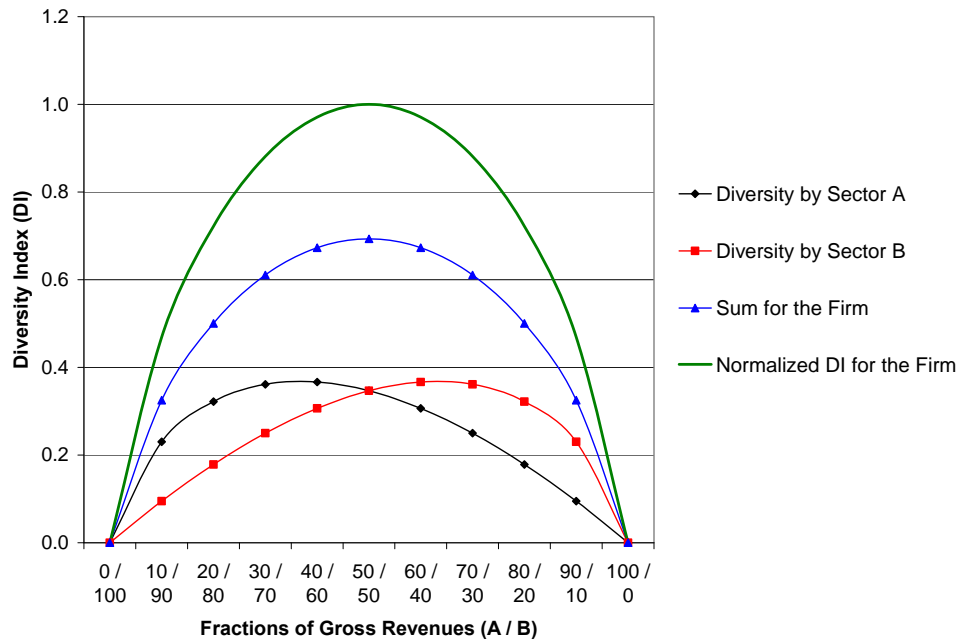


Figure 4.16 Diversity Index for a Firm Operating in Two Sectors

4.5.2 Diversification Pattern of Contractors

The current study analyzes the diversification pattern of large construction contractors using the ENR top 400 Contractors data over the last 14 years from 1994 to 2007. As discussed earlier, the ENR data provide information about each individual firm's gross revenues over eight different market sectors. The entropy measure is applied to measure individual firm's diversification level, which is named firm diversity index.

Figure 4.17 shows the distribution of the ENR top 400 contractors' diversity index. The diversification pattern of the ENR firms has been stable over the last 14 years. In Figure 4.17, low entropy connotes higher specialization and lower market diversification, high entropy indicates the opposite.

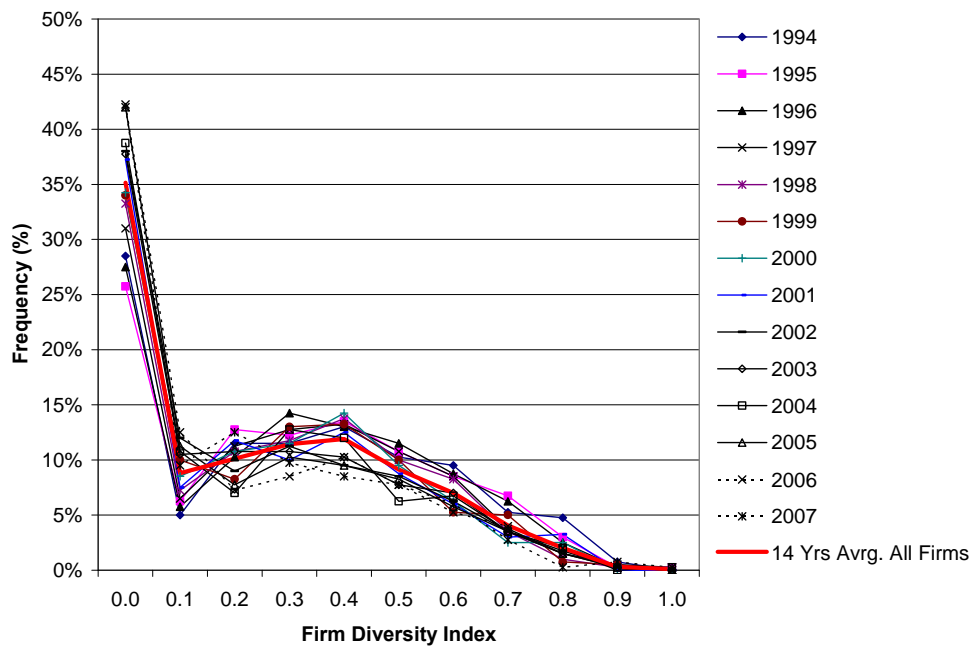


Figure 4.17 Distribution of the ENR Contractors' Diversity Index

On average, over 14 years, about 35% of the firms were fully specialized and about 65% of the firms performed their business in more than one industry sector. Refer to Appendix 3 to have a better view of diversification patterns for each year.

As done for the size distribution of the ENR 400 contractors, the distribution of firm diversity indices can be constructed for only domestic revenue firms to identify any differences that may exist. Figure 4.18 shows the diversity index distributions of the

domestic revenue firms. There are more specialized and less diversified firms among the domestic revenue firms. However, the overall patterns are very similar to each other. Over 14 years, the average number of domestic revenue firms was about 321 of the total 400. Also, refer to Appendix 3 to have a better view of diversification patterns by domestic revenue firms for each year.

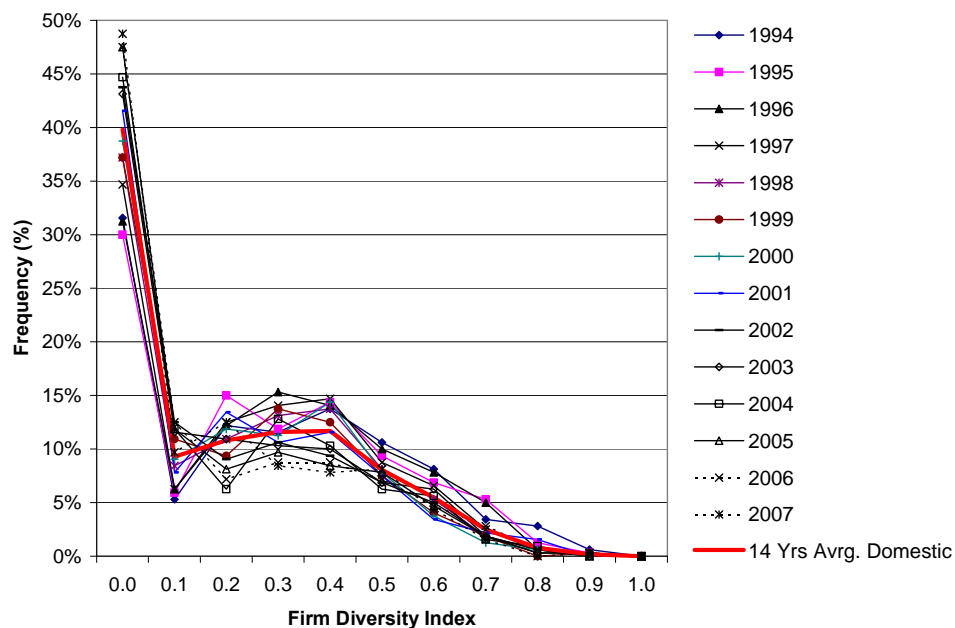


Figure 4.18 Distribution of the ENR Firms Diversity Index (Domestic)

Other than the diversity index, there is a simple way to describe how much the ENR top 400 contractors are diversified into different market sectors: counting the number of sectors in which a firm has revenues. Figure 4.19 shows the distribution of firms by the number of sectors in which firms operate.

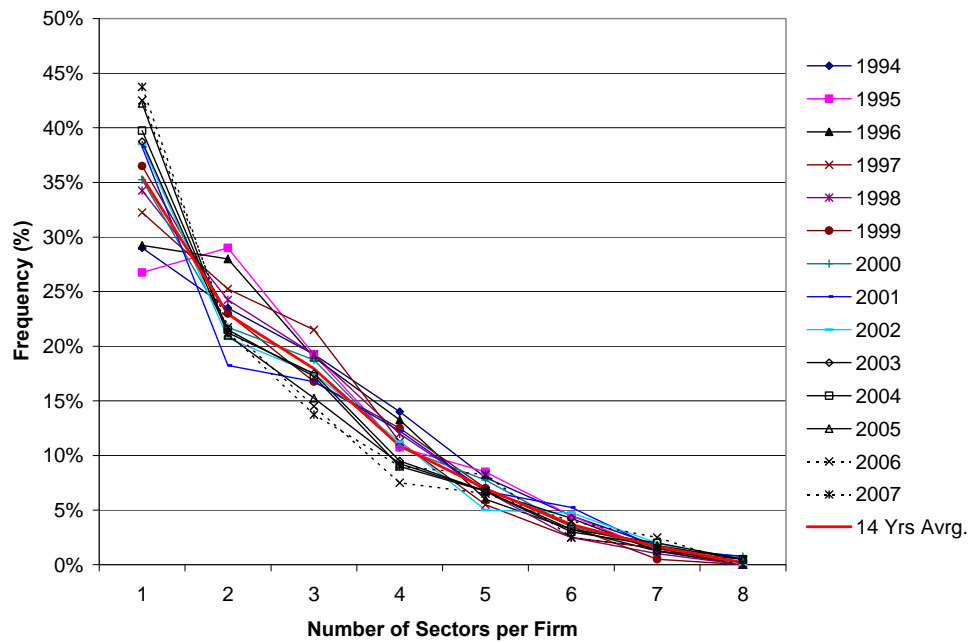


Figure 4.19 Distribution of Firms by the Number of Sectors per Firm

About 35% of the ENR Top 400 contractors have their establishment(s) in only one sector while about 65% of them have establishments across different sectors, which is the same result using the entropy measure (See Figure 4.17). The distributions of the number of establishments per firm are stable over 14 years similar to the diversity index distributions shown in Figures 4.17 and 4.18.

4.6 Summary

To identify aggregate patterns that can be considered as the resultants of competition among individual contractors in a population, Chapter IV analyzed different sources of the U.S. construction industry data:

- *ENR U.S. Top 400 Contractors*
- *2002 Economic Census* by the U.S. Census Bureau
- *Statistics of U.S. Business (SUSB)* by the U.S. Census Bureau

Using the ENR data and 2002 Economic Census data, the current study found a linear pattern in the size distribution of construction firms or establishments. The identified pattern is similar to the pattern that has been found in many biology or ecology studies, indicating that the aggregate pattern is based on competitive processes in the population.

The analysis using the 2002 Economic Census data showed the size distributions for the establishments in the total construction industry as well as in the classified market sectors: building construction, heavy construction, and specialty trades. The same linear patterns were found in each market sector with small differences in slope. On the other hand, different shapes in the size distributions were found for manufacturing firms. For an explanation of the differences found in other industries compared to the construction industry, further investigation would be required.

Contractors' expansion, contraction, death, and birth occur as the results of competition among contractors. Another analysis was performed to identify contractors' organizational changes in employment using the dynamic data in the SUSB. It was

found that construction contractors have higher frequencies and percent changes in employment by all categories of deaths, births, expansions, and contractions compared to the averages for the U.S. total industry. Large contractors that have more than 500 employees experience significant employment expansions and contractions, which indicate significant moves of people between construction firms. The rates are much higher than the U.S. total industry averages for the class of all large firms.

Also, large contractors' market diversification pattern was identified by applying the entropy measure to the ENR U.S. Top 400 Contractors data. About 65% of large contractors among the ENR contractors perform their businesses in more than one industry sector. The other 35% of contractors are specialized in one market sector. The analysis confirms that the diversification pattern is stable over the data periods and is not sensitive by differentiating the population of contractors, i.e., all 400 firms vs. domestic revenue firms.

CHAPTER V

METHODOLOGIES AND DEVELOPMENT OF HYPOTHESES

Chapter V discusses methodologies used in the current investigation and the hypotheses to be tested. The methodologies to be discussed are the evolutionary approach and representation of construction contractors' different risk attitudes. Two methods to represent different risk attitudes are discussed for contractors' go/no-go decisions in competitive bidding. Five hypotheses are proposed to clarify the possibly significant effects of risk attitude on contractors' competitive success.

The procedure in the current investigation can be summarized as follows:

- Develop a new and simple method to represent contractors' risk-taking depending on their own risk attitudes and compare it with the conventional method using expected utility;
- Build a simulation model based on evolutionary theory and represent competition among contractors having different risk attitudes in the model;
- Observe the effects of risk attitude in terms of industry-wide patterns that evolve as results of competition among multiple contractors in the model;
- Compare the model results to the patterns observed in the actual U.S. construction industry data in Chapter IV and confirm that the model successfully predicts industry-wide outcomes based on the comparison; and

- Test hypotheses using the developed evolutionary model and make recommendations for construction contractors.

5.1 Evolutionary Approach

5.1.1 Evolutionary Approach: General

One promising methodology that has been applied in the competition studies is the evolutionary approach, especially in biology, ecology, and market ecology. In this approach, organizations are considered as individual entities competing with each other for common resources for survival. The common resources are limited in their environment, hence scarcity drives the competition among individuals. While being exposed to competitive pressure or selection process, some entities survive and thrive while others shrink or disappear. Differentiation between surviving individuals and failing individuals is determined by organizational or genetic traits in biology or by different economic performances in market ecology. The individuals can be members within a species or between species in biology, firms in organizational ecology, and economic decision makers in economics.

The general approach in these evolutionary studies is to observe aggregate patterns such as distribution of organizations by size or other attributes of individuals in a population and to infer the competitive forces and responses of these individuals from the identified patterns and attributes. Depending on study purposes, interests focused on different issues such as the underlying mechanism of evolution, organizational changes,

entry and exit rates, aggregate patterns that evolve at the population level, and so on. Different mechanisms for organizational changes and industry evolution have been considered. They include organizational innovation (Nelson and Winter (1977); Kwaśnicki (1998)), organizational learning, adaptation, or mutation (Fiol and Lyles (1985); Levinthal (1991)), technical learning (Dosi et al., 1995), etc.

In theoretical foundation, there are still vague concepts or disagreements on the process of selection. Organisms influence their own environments and selection regimes, therefore in such cases boundaries between environmental development and organizational selection are not clear (Erwin and Krakauer, 2004). So, competing individuals could affect the selection process in a population of individuals while the environment affects individual entities in it.

Recently, researchers started paying attention to evolutionary analysis of decision making in competitive environments (Sounderpandian, 2007). Sounderpandian (2007) proposed an evolutionary game theoretic approach assuming competitive bidding situations. The proposed approach allows interactions among players by representing each player's adjustment of his own risk attitudes depending on the actions of neighbors. Sounderpandian (2007) admits that his model is simple and the presented simulations were too simple to produce normative results and proposes extensions of his approach for future studies. Also, it would not be realistic for an organization to change its risk attitude as easily as represented in his approach.

Organizational risk attitude as a part of organizational culture governs organizational activities through integration and patterning an organization's behaviors

and rationales while it is an unconscious and deep part of an organization (Schein, 2004). Risk attitude is embedded in the people in the firm. The firm does not attempt to change people's risk attitude. It hires those with compatible risk attitudes and does not hire (fires) those that do not match the culture. These cultural attributes may be subconscious rather than conscious decision. Therefore, the culture persists and can be changed only with difficulty.

Consider for example a construction firm that is highly risk-averse and does not take jobs using fixed price contracts. For such a firm to change its culture from one in which the contractor takes no risk (using cost plus fee contracts) to one in which the contractor takes all the cost risk (using fixed price contracts) is difficult. Nevertheless, it may be necessary for the firm's survival.

5.1.2 Evolutionary Approach in the Current Study

The current study investigates the effects of organizational risk attitude on competition in the construction industry. Competitive bidding in which contractors obtain their jobs from the market is represented as the mechanism of market competition. It is hypothesized that the heterogeneity in organizational risk attitude leads to differences in contractors' risky decisions (risk-taking behaviors) in competition, and different decisions by contractors would result in differentiated performances through the competition. Also, some aggregate effects could be observed at the industry level since risk-taking under competition is an essential element of construction business for all individual contractors. These dynamics in a population caused by competition in a

market are observed at the population level, whereas it is not easy to observe a specific pattern at the individual firm level.

Within the evolutionary approach, the current study takes multiple perspectives from individual to population levels and a long-term view to consider the process of evolution and the above expected effects. It will reveal underlying linkages between causes and effects between organizational risk attitude and firm performance. Following are issues to be considered at different levels in the current study.

Individual Levels

- Depending on their own risk attitude, individual contractors can perceive the same risky situation differently, and then they can react to it differently;
- Individuals compete with each other to obtain jobs in competitive bidding where they make go/no-go decisions, which depend on their own risk perceptions;
- Individuals' economic performance will be differentiated through the competition; and
- Individuals can grow/diversify or contract and they can also exit a market depending on their own performance over time.

Aggregate Levels

- A population consists of individual contractors competing with each other in a market. And, they share common resources, i.e., construction jobs available in the market.
- Among the population, some contractors are more successful than others. Successful firms survive, grow, diversify, or live longer and others contract in size and fail sooner, which develops aggregate patterns such as the size distribution of contractors, age distribution, overall industry capacity changes, diversification patterns, etc.

In order to take these multiple perspectives, the current study needs to perform the following tasks:

- Representation of differences in risk-taking among contractors depending on their own risk attitudes;
- Representation of competition among multiple contractors assuming competitive bidding environment;
- Measurements of individual contractors' performances;
- Monitoring individuals' organizational changes depending on their financial performance; and
- Monitoring any aggregate-level changes and effects that evolve over periods, if there are any.

The representation of contractors' different risk attitudes and their risk-taking behaviors is discussed in Sections 5.3 through 5.5 in this chapter. Other tasks on the above list are discussed in detail in Chapter VI.

5.2 Risk Attitude in Uncertain Situations

Expected value theory maintains that people make a choice to maximize expected present value of a future event when they face uncertainty. However, people do not always behave as if they were maximizing expected value. Depending on personal differences in their attitude toward uncertainty, some people take the less risky choice while others take the more risky choice even though the choices have the same expected value.

For example, suppose there are two risky choices and the possible consequences of each of the two choices can be described by probability density distributions. The two probability distributions have a same mean, but different variances. Then, there should be no differences in individuals' decisions on these two risky choices according to expected value theory since they have the same expected value (mean). However, some individual would be concerned more about downside uncertainty which is indicated by a long tail (with a greater variance) toward the downside in the probability distribution. This risk-averse individual will choose the alternative with the smaller variance. On the contrary, a risk-seeking individual will choose the other choice with

the larger variance (a long tail toward the upside). If the individual is risk-neutral, the variance does not matter.

To resolve this discrepancy between how people actually behave and the behaviors based on expected value theory, von Neumann and Morgenstern (1944) focused on expected utility theory in their book *The Theory of Games and Economic Behavior*. Utility theory allows different risk attitudes for individuals and explains how individuals make different decisions under an identical risky situation. Details on the expected utility theory and utility functions are discussed in Section 5.3.

Later, Kahneman and Tversky (1979) introduced prospect theory and proposed a modified shape of utility function to overcome the criticisms of utility theory that people have inconsistent preferences about gain and loss: the certainty effect and the isolation effect. By the certainty effect, people underweight outcomes that are merely probable in comparison with outcomes that are certain. By the isolation effect, people tend to ignore components shared by different choices under consideration, so people focus on distinctive components between choices. Kahneman and Tversky (1979) found that these tendencies lead to inconsistent preferences with respect to the same risky choice when the choice is presented in different forms. To represent these effects, the value function proposed in prospect theory portrays different evaluations of prospects: concave function for gains and convex function for losses. Refer to Kahneman and Tversky (1979) for details.

Both expected utility theory and prospect theory are complex and they are difficult for practitioners to understand and use for a real decision. And, the

development of a utility function with concave and/or convex curvatures for individuals could be difficult and somewhat arbitrary. Also, a firm's risk attitude may be implicit in the corporate culture and not explicitly identified. Due to these difficulties, empirical studies using actual data have been limited. An easy and simple method needs to be devised to deal with construction contractors' risk attitude for real applications.

In economics, management studies found the presence of heterogeneity in risk attitude among firms (Pennings and Smidts, 2000; 2003). Managers' different risk attitudes can explain the differences in how firms do their business, especially in trading behaviors (Pennings and Smidts, 2000) and the global shape of a decision maker's utility function reflects his strategic decision structure (Pennings and Smidts, 2003). Risk attitude of an organization is a part of organizational culture and it governs organizational behaviors in risk-taking in business. Consequently, questions can be raised about the effects of heterogeneity in risk attitude on the differences in the performance among economic organizations.

Sections 5.3. and 5.4. discuss how to represent different risk attitudes using two different methods: the conventional method using expected utility and a new method proposed in the current study using Value at Risk. In Section 5.5, the current study tests these methods to describe contractors' risk-taking behaviors, i.e., go/no-go decisions in competitive bidding.

5.3 Expected Utility Theory and Utility Functions

In the literature, differences in risk preference among individuals or organizations have been described using expected utility theory and utility functions (von Neumann and Morgenstern, 1944). Expected utility theory is prescriptive: a decision maker is supposed to choose the policy that maximizes his expected utility over all possible outcomes.

5.3.1 *Expected Utility Theory*

Using expected utility theory, different risk attitudes are classified into risk-averse, risk-neutral, and risk-seeking, each of which is discussed below.

Representation of Different Risk Attitudes

Consider a hypothetical situation as follow. A variable x can be x_1 or x_2 with probability p and $(1-p)$. The expected value of this random condition is defined in Equation 5.1.

$$E[x] = px_1 + (1-p)x_2 \quad [5.1]$$

Let $U(x)$ be a utility function of x , the function that a decision maker tries to maximize. The expected utility is defined as in Equation 5.2.

$$E[U(x)] = pU(x_1) + (1-p)U(x_2) \quad [5.2]$$

A special condition when expected value theory and expected utility theory provide the same result is explained below. This applies when an individual or an organization is risk-neutral. According to expected value theory, $E(x)$ is a linear combination of x_1 and x_2 as in Equation 5.1, which can be seen on the x axis in Figure 5.1. Figure 5.1 has a straight line AEB, which is a utility function. If $U(x) = x$, then $U(x_1) = x_1$, $U(x_2) = x_2$, and $E[U(x)] = E[x]$, as shown on the y axis. Thus, expected utility is identical to expected monetary value.

Consider two lotteries:

- Lottery 1 pays the expected value $E(x) = px_1 + (1-p)x_2$ with certainty.
- Lottery 2 pays either x_1 with probability p or x_2 with probability $(1-p)$.

If a decision maker has the utility function in Figure 5.1, the individual will be indifferent between the two lotteries and the individual is called risk-neutral. Therefore, a risk-neutral decision maker will make a choice as consistent with expected value theory.

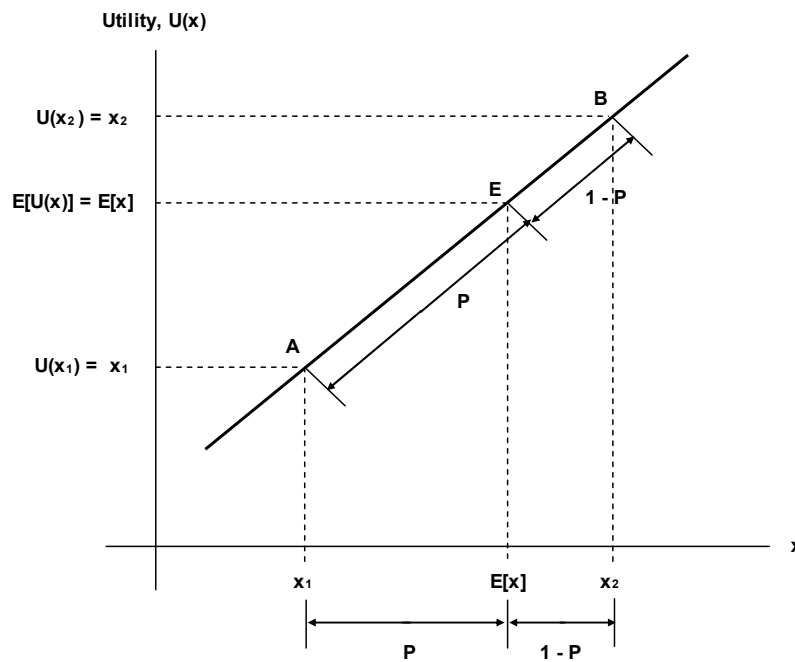


Figure 5.1 Utility Function – Risk-neutral

Next, consider a risk-averse decision maker who has a concave utility function such as the curve ACDB in Figure 5.2. Figure 5.2 describes how $E[x]$ and $E[U(x)]$ can be different and how a decision can be made differently depending on individuals' risk attitude, in particular the risk-averse case. In the figure, A is the point on the utility function corresponding to $U(x_1)$. B is the point on the utility function corresponding to $U(x_2)$. On the curve ACDB, the point D corresponds to $U[E(x)]$, the utility of the expected value. Meanwhile, the point C corresponds to $E[U(x)]$, the expected value of the utility.

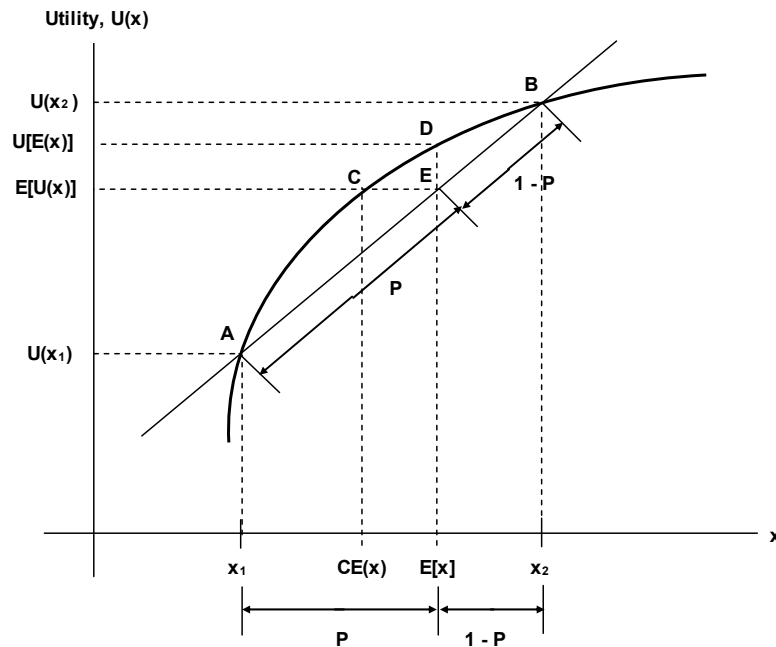


Figure 5.2 Utility Function – Risk-averse

As shown on the y axis in Figure 5.2, $U[E(x)]$ is greater than $E[U(x)]$ as in Equation 5.3. Using Equations 5.1 and 5.2, Equation 5.4 is derived.

$$U[E(x)] > E[U(x)] \quad [5.3]$$

$$U(px_1 + (1-p)x_2) > pU(x_1) + (1-p)U(x_2) \quad [5.4]$$

Equations 5.3 and 5.4 explain that the utility of the expected value is greater than the expected value of the utility using the concave utility function in Figure 5.2.

Consider again the same lotteries discussed above now for a risk-averse decision maker.

- Lottery 1 pays the expected value $E(x) = px_1 + (1-p)x_2$ with certainty.
- Lottery 2 pays either x_1 with probability p or x_2 with probability $(1-p)$.

As described in Equation 5.4, the utility that the risk-averse decision maker will have, if he/she obtains $E(x)$ with certainty, is greater than expected value of the combination of $U(x_1)$ and $U(x_2)$ with probability p and $(1-p)$. Therefore, this decision maker will choose lottery 1. The decision maker prefers certainty to uncertainty even though lottery 2 could pay more.

In contrast, for a risk-seeking decision maker, if such an individual exists, the utility that the decision maker will have, if he/she obtains $E(x)$ with certainty, is smaller than expected value of the combination of $U(x_1)$ and $U(x_2)$ with probability p and $(1-p)$. Therefore, the decision maker will choose lottery 2. The decision behaviors by a risk-seeking decision maker can be represented by a convex curve, which has the mirror image of the concave curve against in the straight utility function AED in Figure 5.2.

Risk Premium

For a risk-averse decision maker, $U[E(x)] > E[U(x)]$. The decision maker perceives $U[E(x)]$ more valuable than $E[U(x)]$. How much more does the decision maker value $U[E(x)]$ than $E[U(x)]$? The equivalent amount of monetary value when the decision maker chooses Lottery 1 is $CE(x)$, the certainty equivalent of x , which can be calculated using an inverse function, as shown in Figure 5.2. If the difference between $E(x)$ and $CE(x)$ is paid to the risk-averse decision maker, the decision maker would be willing to take the risky choice, lottery 2. In fact, the decision maker becomes indifferent between the two lotteries. The difference between the expected value and $CE(x)$ is called the risk premium (RP) as in Equation 5.5.

In order to let a risk-averse decision maker choose Lottery 2 instead of Lottery 1, someone needs to pay the risk premium to the risk-averse decision maker. In general, without providing the risk premium or extra benefit, the risk-averse decision maker would not choose a risky choice (lottery 2 in this example).

$$RP(x) = E[x] - CE(x) \quad [5.5]$$

Therefore, different risk attitudes can be classified by the value of the risk premium as below:

- $RP(x) > 0$ for all values of x for a risk-averse individual or organization
- $RP(x) = 0$ for all values of x for a risk-neutral individual or organization
- $RP(x) < 0$ for all values of x for a risk-seeking individual or organization

5.3.2 *Utility Functions*

There are different types of utility functions used in the literature. As explained above, the utility function is a function that a decision maker maximizes in his/her choice. So, a utility function depends on an individual's risk preference. Note that once $U(x)$ has been defined, making a decision is a purely mathematical operation (optimization) and no choice is left to the decision maker. Consequently, if $U(x)$ is known, the decision made by the decision maker can be predicted with perfect accuracy.

Frequently used utility functions are exponential functions, power functions, and quadratic functions. Among them, exponential functions (Pratt, 1964) are most frequently used (Walls and Dyer, 1996), and are discussed below.

The general form of exponential utility functions is found in Equation 5.6.

$$U(x) = a - e^{-cx} \quad (0 \leq x \leq \infty) \quad [5.6]$$

Where, a is a constant to make the utility positive (if so desired); and c is the risk-aversion coefficient. $c = 0$ indicates risk-neutrality and large values of c indicate greater risk-aversion (greater curvature of the utility function).

The coefficient c is to decide the degree of risk-aversion. The main reason for the frequent use of these exponential functions is their simplicity: the function needs only one parameter, the risk-aversion coefficient c . Figure 5.3 provides a set of exponential functions with different risk-aversion coefficient values and the constant $a = 1$, for example. Utility functions of real people would vary.

In Figure 5.3, as the risk-aversion coefficient c increases, the functions have more curvature, which means that $U[E(x)]$ becomes higher than $E[U(x)]$, requiring greater amount of risk premium for a risk-averse decision maker. A more concave curvature in a utility function represents a more risk-averse attitude.

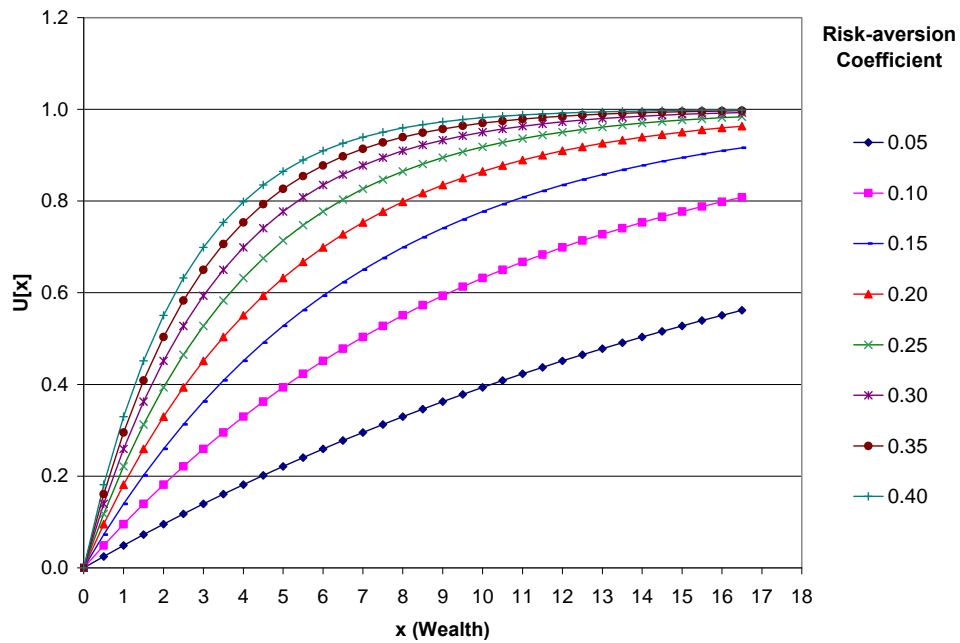


Figure 5.3 Example of Exponential Utility Functions (Risk-averse Case)

5.4 Value at Risk and Maximum Loss Allowance

The current study proposes a new and simple method to represent contractors' risk-taking behaviors depending on different risk attitudes using VaR and maximum loss allowance.

5.4.1 Value at Risk (VaR)

Value at Risk traces its origin to the infamous financial disasters of the early 1990s that made people concerned about how much possibly can be lost in the financial market. VaR measures the expected amount of loss over a given time horizon. VaR is

being adopted by many financial institutions (Jorion, 2001). The advantage of using VaR is that it summarizes the downside risk in a simple manner, the amount of possible loss, i.e., dollars. VaR can be used to describe business managers' perceptions of risks since managers usually perceive their business risk as exposure to possible losses and levels of risk are expressed by the amount of possible loss. This concept should be easily understood by construction practitioners.

Suppose a case when a contractor has his budget for a task to be performed and the actual cost of the task is not known. The contractor suffers a loss if the actual cost of the task is greater than the budget. Let x be the actual cost of the task and $f(x)$ the probability density function of the actual cost. So, the possible outcomes may have a probability distribution as shown in Figure 5.4.

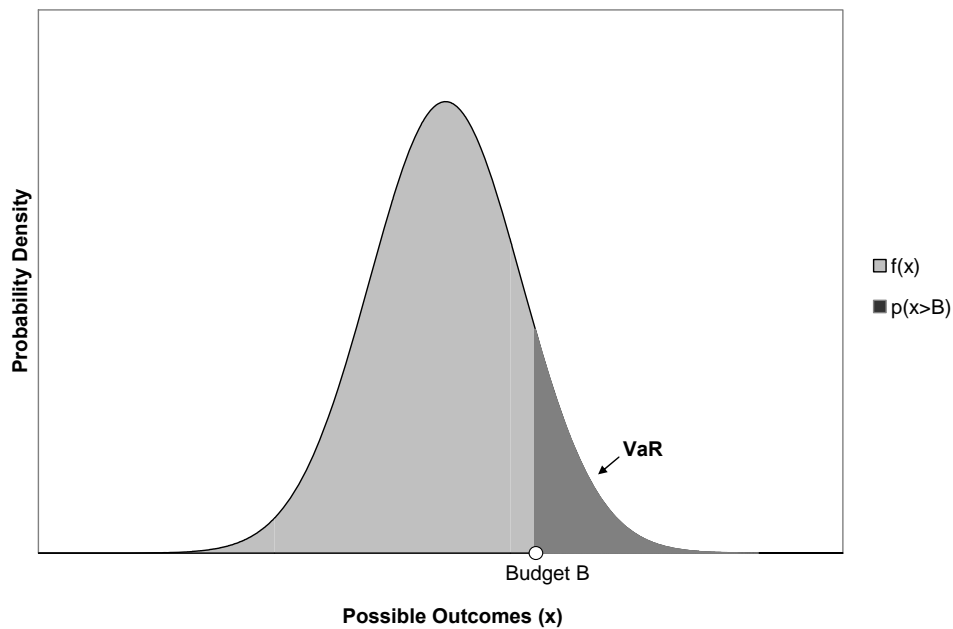


Figure 5.4 Probability Distribution of Possible Outcomes

The expected value of the actual cost is calculated using Equation 5.7.

$$E[x] = \int_{-\infty}^{\infty} xf(x)dx \quad [5.7]$$

The decision maker has budget B for the task. The probability that the actual cost overruns the budget B is calculated using Equation 5.8 to account for the shaded right-hand side tail in Figure 5.4, the probability that $x \geq B$ for all values of x .

$$P\{x > B\} = \alpha = \int_B^{\infty} f(x)dx \quad [5.8]$$

The possible overruns beyond budget B and the probabilities that the overruns occur can be combined for the calculation of *the expected value of loss* as in Equation 5.9. It is the integration of the products of cost overrun and corresponding probabilities. In other words, Value at Risk represents the combined effects of undesirable results (cost overruns) and the probabilities of cost overruns. This method describes how real contractors express risks: they express business risks in dollars not in utiles (units of utility).

$$VaR = \int_B^{\infty} xf(x)dx \quad [5.9]$$

5.4.2 *Maximum Loss Allowance (MLA)*

One of the important decision criteria for a go/no-go decision would be how much loss a contractor can allow from a job under bid. The possible loss from a job can be measured using VaR. An individual contractor may have its own decision standard when it makes this risky decision. If the possible loss from a job is expected to be greater than the firm's decision standard, the firm would decide not to bid and to wait for new jobs. In the opposite case, the firm would decide to bid.

By defining the amount of possible loss that a firm is willing to allow in its risky choice, the firm's decision standard can be expressed in a quantitative measure. Then, the measure describes how much risk-averse or risk-tolerant a firm is. For example, more risk-averse firms allow small amounts of possible loss in their risky decision situations. In contrast, more risk-tolerant firms are willing to accept possibly large risks for potentially large profits. Therefore, individuals' different risk attitude can be defined by the amounts of possible loss that each individual allows in his/her risky choice.

The current study proposes a new term to describe this decision criterion of contractors, *Maximum Loss Allowance*, defined as the maximum amount of loss that a contractor allows for a job. Using this concept, different risk attitudes for contractors are represented in a quantitative measure (in dollars) in the model. Using the new term, more risk-averse contractors have small values of MLA while more risk-tolerant contractors have large values of MLA.

5.5 Contractors' Go/No-go Decision

This section explains two different methods to present contractors' different risk-taking behaviors in their go/no-go decision. In the conventional method using expected utility, different risk attitudes are classified into three generic types: risk-averse, risk-neutral, and risk-seeking. Meanwhile, the proposed new method describes different risk attitudes of contractors by different amounts of maximum loss allowances, which represent various degrees of risk attitude, i.e., how much risk-averse or risk-tolerant a contractor is.

5.5.1 *Go/No-go Decision Using Utility Functions*

Consider a contractor that decides the fixed price of a job before performing the job. The actual cost of the job is subject to uncertainties at the time of decision and the true cost will be determined at the completion of the job. The contractor is responsible for all cost risks (actual cost greater than the price) and the owner takes no cost risk. The contractor's price setting is a risky task since the contractor does not know the actual cost of the job. But, the contractor has some knowledge about possible range of actual cost and probability, i.e., a probability distribution of actual cost, as in Figure 5.4.

Let the expected cost of the job be $E(x)$, which is based on contractors' probability distributions. In the go/no-go decision for a job, a risk-neutral contractor would proceed to bid at a bid equal to $E(x)$, which has a 50% chance of gain and a 50% chance of loss. The contractor's go/no-go decision simply depends on $E(x)$, which is

based on expected monetary value theory. The contractor would not care about downside and upside uncertainties.

However, risk-averse or risk-seeking contractors would have different perceptions on the downside and upside uncertainties. A risk-averse contractor would proceed to bid if its bid is greater than $E(x) + \text{its risk premium}$. On the other hand, a risk-seeking contractor would proceed to bid unless its bid amount is smaller than $E(x) - \text{its risk premium}$. The amount of risk premium varies depending on the degrees of risk-aversion or risk-seeking of the contractors. So, contractors having different risk attitudes would have different budget thresholds in their bid decision, which can be represented by $E(x) \pm \text{risk premium}$.

Utility functions can be used to represent these contractors' different risk attitudes and to quantify the magnitude of risk premiums. In the following description, for simplicity of comparison, it is assumed that all jobs are identical and bid decisions by contractors are independent and repetitive. Then, contractors' utility functions need to be normalized so that possible values of utility lie between utility zero and utility 1.0. This normalization is a common method to apply utility functions for different individuals evaluating the same subject. Equation 5.10 shows the normalized exponential utility function. The shape of utility functions varies depending on the value of risk-aversion coefficient r as listed in Table 5.1.

$$\begin{aligned}
 \text{if } r \neq 0, U(x) &= \frac{1 - \exp(-(x-a)r)}{1 - \exp(-(b-a)r)} \\
 \text{if } r = 0, U(x) &= \frac{(x-a)}{(b-a)}
 \end{aligned}
 \tag{5.10}$$

Where, r is the risk-aversion coefficient to define risk attitude;

x is the wealth (contractor's bid) and $x > 0$;

a is the minimum value of wealth (associated with the minimum bid); and

b is the maximum value of wealth (associated with the maximum bid).

Table 5.1 Risk-aversion Coefficient and Characteristic of Utility Functions

Value of coefficient	Curvatures	Risk attitudes
$r > 0$	Concave	Risk-averse
$r = 0$	Straight	Risk-neutral
$r < 0$	Convex	Risk-seeking

Figure 5.5 provides an example of the normalized utility functions. The assumed value of expected cost $E[x]$ is \$10M. A contractor's minimum bid that attains the minimum utility (0.0) and the maximum bid that attains the maximum utility (1.0) are assumed to be \$6.0M (the value of a) and \$14.0M (the value of b) in Equation 5.10, respectively. As shown in Figure 5.5, positive values of the risk-aversion coefficient develop concave curves, indicating risk-aversion. In contrast, negative values of the coefficient develop convex curves, indicating risk-seeking.

Individual contractors could have different estimates for an identical job even if they have similar levels of estimating capability. A contractor's bid may take any value within the ranges specified on the x axis in Figure 5.5.

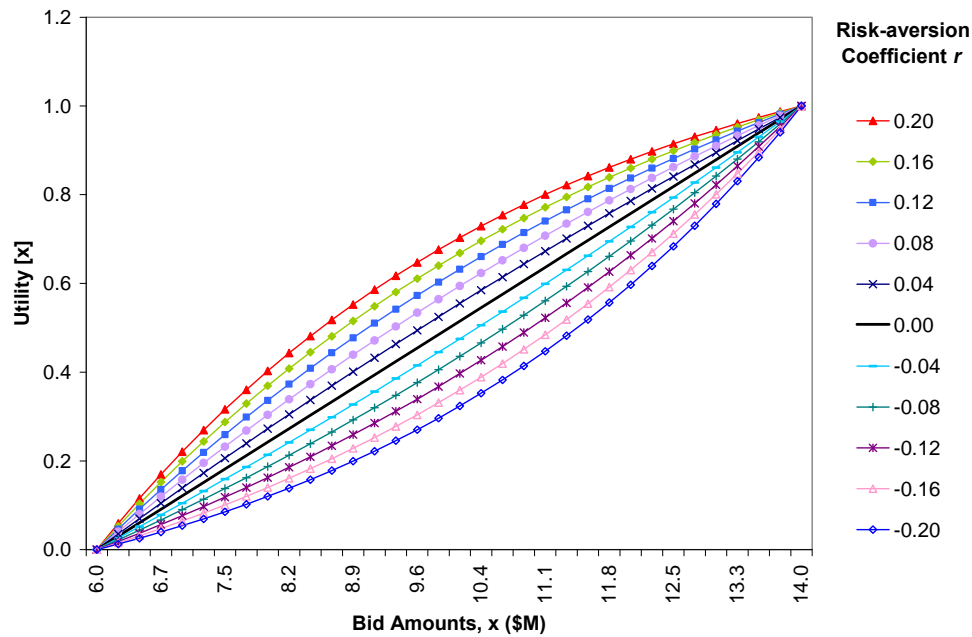


Figure 5.5 Example of Normalized Exponential Functions

Calculation of Risk Premium

This section provides a detailed procedure for the estimation of the risk premium for contractors that have different risk attitudes using the normalized exponential utility functions as follows:

- 1) Define a contractor's utility function by choosing a value of risk-aversion coefficient r .
- 2) Assume a probability distribution of actual cost and define the expected cost of the job, $E(x)$ from the distribution. Also, define the maximum and the minimum values for wealth in Equation 5.10.
- 3) Calculate the utility of the expected cost, $U[E(x)]$ using the normalized utility function with the specified coefficient r .

- 4) Calculate the expected value of the utility of x , $E[U(x)]$ using the normalized utility function with the coefficient $r = 0$ (risk-neutral).
- 5) Calculate the certainty equivalent (CE) using the inverse function of the utility function. Equation 5.11 is the general form of the inverse function of the normalized exponential utility function defined in Equation 5.10.

$$\begin{aligned} \text{if } r = 0, x &= y(b-a) + a \\ \text{if } r \neq 0, x &= a - \frac{1}{r} \left[\text{LN} \{1 - U(x)(1 - \exp(-(b-a)r))\} \right] \end{aligned} \quad [5.11]$$

- 6) Calculate the risk premium: $RP = E(x) - CE$

The value of the risk premium can be positive, negative, or zero, depending on the individual contractor's risk attitude.

- 7) Calculate budget threshold: $BT = E(x) + RP$

Then, go/no-go decisions by an individual contractor can be made given the contractors' bid amount considering the individual's risk attitude. The decision is based on the comparison of the bid amount with the individual's own budget threshold as below:

- Proceed to bid, if the bid amount $\geq BT$ since the contractor perceives the risk acceptable.
- Decline to bid, if the bid amount $< BT$ since the contractor perceives the risk unacceptable.

5.5.2 Go/No-go Decision Using Value at Risk

Suppose a contractor has its budget for a job. The contractor's bid amount will be its budget when it bids and wins the job. The contractor will suffer a loss if the actual cost of the job turns out to be greater than its budget (contract price). But, the contractor will gain a profit in the opposite case. So, there are uncertainties in the contractor's decision; downside uncertainties of losses and upside uncertainties of gains.

VaR can be calculated as follow. First, consider a unit normal variate t . t is distributed as the normal variate with mean = 0 and standard deviation = 1. The unit normal probability density function is shown in Equation 5.12.

$$f(\tau) = \frac{e^{-\tau^2/2}}{\sqrt{2\pi}} \quad [5.12]$$

For simplicity, connote this unit normal function as $\phi(t)$. Given some budget B , the probability α that actual cost overruns k is the area under the Unit Normal curve from $t = B$ to $t = \infty$ is

$$\alpha = \int_B^{\infty} \phi(\tau) d\tau \quad [5.13]$$

and the VaR for this unit normal is

$$VaR = \int_B^\infty \tau \phi(\tau) d\tau = \int_B^\infty \frac{1}{\sqrt{2\pi}} e^{-\tau^2/2} d\tau \quad [5.14]$$

We may take note of the identity:

$$\int e^u du = e^u \quad [5.15]$$

Letting $u = -\tau^2/2$, substituting this into Equation 5.14, and then applying Equation 5.15 gives:

$$\begin{aligned} du &= -\tau d\tau \\ \int_B^\infty \frac{1}{\sqrt{2\pi}} e^{-\tau^2/2} d\tau &= \int_B^\infty -\frac{1}{\sqrt{2\pi}} e^u du = -\frac{1}{\sqrt{2\pi}} e^u \\ &= -\frac{1}{\sqrt{2\pi}} e^{-\tau^2/2} \Big|_B^\infty = \phi(B) \end{aligned} \quad [5.16]$$

Therefore, the Value at Risk function for the unit normal distribution is simply the value of the unit normal as shown in Equation 5.17. Figure 5.6 shows α and VaR for the unit normal distribution. In the figure, VaR increases as the budget amount decreases, *and vice versa*.

$$VaR = \phi(B) \quad [5.17]$$

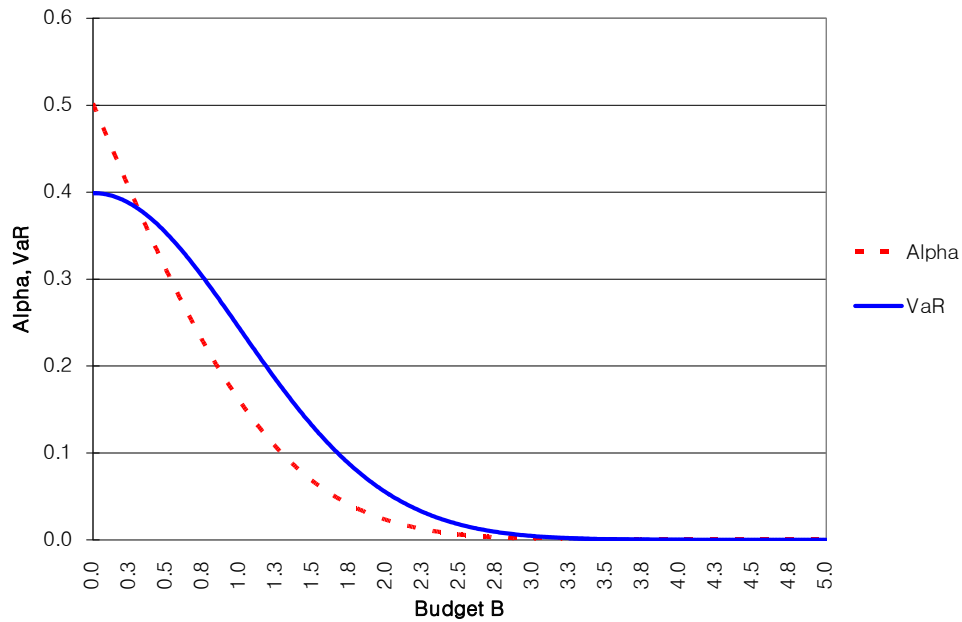


Figure 5.6 Alpha & VaR for Unit Normal Distribution

In most cases, normal variates such as cost are more interesting than unit normal variates. Suppose x to be the cost which follows a Normal distribution $N(\mu_c, \sigma_c^2)$.

Define the unit normal variate t as in Equation 5.18.

$$t = \frac{x - \mu}{\sigma} \quad [5.18]$$

Then, $x = \mu + \sigma t$; $dx = \sigma dt$

Suppose a budget B is k standard deviations above the mean. Then,

$$\begin{aligned}
 k\sigma &= B - \mu, \\
 \therefore k &= \frac{B - \mu}{\sigma}
 \end{aligned}
 \tag{5.19}$$

It was found that Value at Risk function for the unit normal distribution is simply the value of the unit normal as shown in Equation 5.17. Substituting k with the budget B gives Equation 5.20:

$$\alpha = \int_k^\infty \phi(\tau) d\tau = \int_k^\infty \phi\left(\frac{x - \mu}{\sigma}\right) \frac{dx}{\sigma} = \int_k^\infty f(x) dx
 \tag{5.20}$$

In a similar way,

$$\begin{aligned}
 \int_k^\infty \tau \phi(\tau) d\tau &= \int_k^\infty \left(\frac{x - \mu}{\sigma}\right) \phi\left(\frac{x - \mu}{\sigma}\right) \frac{dx}{\sigma} = \frac{1}{\sigma} \int_B^\infty (x - \mu) f(x) dx \\
 &= \frac{1}{\sigma} \int_B^\infty xf(x) dx - \frac{\mu}{\sigma} \int_B^\infty f(x) dx = \frac{1}{\sigma} \int_B^\infty xf(x) dx - \frac{\mu\alpha}{\sigma} \\
 \therefore \int_k^\infty \tau \phi(\tau) d\tau &= \frac{1}{\sigma} \int_B^\infty xf(x) dx - \frac{\mu\alpha}{\sigma} = \frac{1}{\sigma} \left(\int_B^\infty xf(x) dx - \mu\alpha \right)
 \end{aligned}
 \tag{5.21}$$

For VaR,

$$VaR = \int_B^\infty xf(x) dx = \sigma \int_k^\infty \tau \phi(\tau) d\tau + \mu\alpha = \sigma\phi(k) + \mu\alpha
 \tag{5.22}$$

Now, Value at Risk can be calculated for any normal distribution with mean and variance by evaluating:

$$\begin{aligned}
 k &= \frac{B - \mu}{\sigma} \\
 \alpha &= 1 - \Phi(k) \\
 \phi(k) \\
 VaR &= \sigma\phi(k) + \mu\alpha
 \end{aligned}
 \tag{5.23}$$

Where, $\Phi(k)$ is the cumulative unit normal probability function.

To make a go/no-go decision for a job, a contractor estimates Value at Risk based on its cost estimate. If VaR associated with the bid amount is greater than the contractor's MLA, the contractor would not bid for the job because the contractor does not allow risks greater than its maximum loss allowance.

In the opposite case, if VaR associated with the bid amount is smaller than the contractor's MLA, the contractor will bid because the contractor allows risks smaller than its maximum loss allowance. The contractor will bid while expecting potential profits under the assumption that the possible loss would not be significant from his own perspective: $VaR < \text{its own MLA}$. However, obviously, the contractor does not know the actual cost when it makes this decision.

Figure 5.7 simplifies the go/no-go decision discussed. Contractors decide to bid or not to bid depending on their own risk attitude that is represented by their own maximum loss allowances. The decision is based on the comparison between the

contractor's own maximum loss allowance and the amount of expected loss from a job (Value at Risk), which is subject to their own estimates.

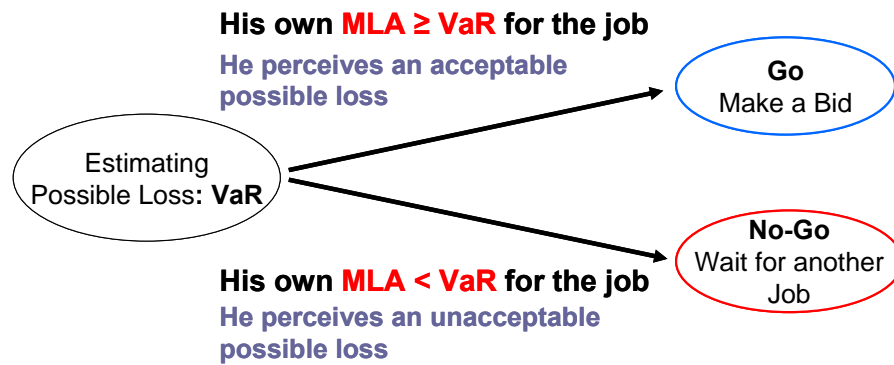


Figure 5.7 Representation of Go/No-go Decision Making

Setting a target or reference points for decision makers in the proposed method for contractors' go/no-go decision making is consistent with the ideas found in recent studies in behavioral decision theory. These studies maintain that individuals use their targets, or reference points in evaluating risky choices (Fiegenbaum and Thomas, 1988). The proposed method is simple and easy for practitioners to understand compared to the alternate method using expected utility and concave or convex utility functions.

5.6 Development of Hypotheses

Heterogeneity in contractors' risk attitudes can be illustrated within a spectrum from the most risk-tolerant to the most risk-averse. For simplicity in comparison, since

how much more or less risk-tolerant/risk-averse is a relative measure, in the current study, different risk attitudes are grouped using relative classifications:

- Most (or highly) risk-tolerant;
- Moderately risk-tolerant;
- Moderately risk-averse; and
- Most (or highly) risk-averse.

In competitive bidding, there are always possibilities of profit/loss from a job. If a contractor anticipates a large amount of possible loss from the job, the contractor does not bid and waits for another job. Otherwise, the contractor would make a bid. The contractor's anticipation is affected by his perception of risk. Thus, the contractor's go/no-go decision depends on his own risk attitude, i.e., how much possible loss he allows in his risky decision.

Using the above classification, most risk-tolerant contractors accept large risks in order to gain potentially high profits. Moderately risk-tolerant contractors behave similarly, but they accept smaller risks than most risk-tolerant contractors. Both types of contractors have larger amounts of MLA than risk-averse contractors. In contrast, most risk-averse and moderately risk-averse contractors avoid the risks of large losses, but simultaneously they lose opportunities for large profits. These contractors are similar, but moderately risk-averse contractors are less risk-averse so that they accept some minimum level of risks more than most risk-averse contractors. These contractors have smaller amounts of MLA than risk-tolerant contractors.

Assuming that contractors' cost estimates are randomly drawn from a same distribution $N(\mu_e, \sigma_e^2)$, which means no difference in their estimation capability, extensions of the above idea follow:

- Risk-tolerant firms would bid more often than risk-averse firms because they allow larger amounts of possible loss, and the bids from risk-tolerant firms would tend to be lower on average than those from risk-averse firms. Hence, they win more jobs;
- Compared to most risk-averse and moderately risk-averse firms, most risk-tolerant and moderately risk-tolerant firms would obtain more jobs while having lower profits per job on average. Sometimes most risk-tolerant firms would suffer large amounts of losses. Moderately risk-tolerant firms are also exposed to the risks of large losses, but less than the most risk-tolerant firms; and
- Compared to most risk-tolerant and moderately risk-tolerant firms, most risk-averse and moderately risk-averse firms would enjoy higher profits per job while obtaining a smaller number of jobs. Sometimes most risk-averse firms would suffer losses due to continuing overhead burden with too few jobs to cover it. Similarly, moderately risk-averse firms are also exposed to risk of overhead burden, but less than the most risk-averse firms.

Table 5.2 provides the relative classification of risk attitude and descriptions for each group. Most risk-tolerant contractors would enjoy high success rate, but could suffer low average profit per job and possible large losses. In contrast, most risk-averse

contractors would enjoy high average profit per job, but could suffer low success rate and high overhead burden. Each of the extreme risk attitude groups has its own advantages and disadvantages as listed in the table.

High overhead burden is expected for most risk-averse contractors if they do not obtain enough jobs while they are reluctant to contract their capacity. Maintaining capacity level requires contractors to spend a fixed amount of money on overhead for personnel, space, etc., even though they do not utilize their capacities.

Table 5.2 Relative Classification of Different Risk Attitudes

	Most (Highly) Risk-tolerant	Moderately Risk-tolerant	Moderately Risk-averse	Most (Highly) Risk-averse
Characteristics	Accept large risks in order to gain potentially high profits	Between the two extremes (most risk-tolerant and most risk-averse)		Avoid risks of large losses, but may lose opportunities for large profits by not bidding or bidding too high
Maximum Loss Allowance	Largest MLA	Relatively Large MLA	Relatively Small MLA	Smallest MLA
Bid Frequency	Bid more often since they tend to make go decisions frequently	Relatively often	Relatively less often	Bid less often since they tend to make no-go decisions frequently
Bid Amounts	Low	Relatively low	Relatively high	High
Success Rate	High	Trade-offs between the two extremes		Low
Average Profit per Job	Low			High
Possible Threats	Possible large losses on projects			Overhead burden

In Table 5.2, moderately risk-tolerant and moderately risk-averse contractors locate between the two extreme risk attitudes. These contractors would make trade-offs

between the advantages and disadvantages of the extreme risk attitudes. The following hypotheses are proposed about expected relationships between contractors' risk attitude and their performances.

H1. Profitability vs. Risk Attitude: Moderately risk-averse contractors have more firm profits than other contractors.

For a contractor to be most risk-tolerant or most risk-averse, there are apparent advantages as well as disadvantages: more jobs with lower profit per job *versus* higher profit per job with fewer jobs. Moderately risk-tolerant contractors are exposed to risks of large losses, even though their risks are smaller than those of most risk-tolerant contractors. In the highly risky construction business, a large loss could affect a firm badly. Being moderately risk-averse could be beneficial in the trade-offs between the profit per job and the amount of jobs won. These contractors avoid risk of large losses. Moderately risk-averse contractors could have overall higher profits than most risk-tolerant, moderately risk-tolerant, and most averse contractors.

H2. Survival vs. Risk Attitude: Moderate risk-aversion is advantageous for survival in the construction market.

Moderately risk-averse contractors could avoid the disadvantages of being most risk-tolerant or most risk-averse: either a large amount of possible loss or a small amount of jobs won under overhead burden, which could result in financial problems. While moderate risk-tolerance assumes risk of large losses that could result in firm failure,

moderate risk-aversion could decrease risks of overhead burden by taking relatively more risks than most risk-averse contractors. Therefore, moderately risk-averse contractors would have more stable business operations and would survive longer.

H3. Growth vs. Risk Attitude: Moderate risk-aversion is in favor of growth in the construction market.

Most risk-tolerant contractors would have difficulty in growing due to the volatility in profitability even though they could obtain higher market share. Most risk-averse contractors would also have difficulty in growing because they would not bid often to obtain more jobs: they are selective in bidding. But, thanks to the stability in business (as proposed in Hypothesis 2 and more overall profits (as proposed in Hypothesis 1), moderately risk-averse contractors could accumulate financial resources, spend them for expansions, and continue stable operation without putting assets at risk by accepting risky jobs.

H4. Diversification vs. Risk Attitude: Moderate risk-aversion is in favor of diversification.

Goals of market diversification can vary: firms can diversify to reduce diversifiable market risks, to grow, or to improve profitability. Whatever the goal of diversification by a firm is, diversification means additional competition by opening new establishments in new sectors. The success of diversification will depend on how a new establishment competes in a new sector. Establishments within a firm inherit the

organizational characteristics including corporate risk attitude. Then, based on the reasoning in H1 and H2, moderately risk-averse establishments would perform better in terms of profitability and survival. Therefore, moderately risk-averse contractors would have higher probability of success in their diversification than most risk-tolerant, moderately risk-tolerant, and most risk-averse contractors.

H5. Diversification vs. Survival: More diversified contractors have longer longevity.

A firm's establishments can share and develop together with the parent firm's financial resources. If moderately risk-averse contractors are successful in diversification as proposed in H4 and they survive longer as proposed in H2, more diversified firms would enjoy longer longevities. Every contractor may have bad years and good years. But, for diversified contractors, they have more chance to survive when their businesses go bad since they have their establishments as multiple buffers against firm failure.

5.7 Summary

Chapter V presented detailed descriptions of the methodologies and the hypotheses developed for the current study. The procedure in the current investigation is summarized as follows:

- Build a simulation model based on evolutionary theory and represent competition among contractors having different risk attitudes;
- Observe the effects of risk attitude in industry-wide patterns that evolve as results of competition in the model and compare the model results to the patterns observed in the actual U.S. construction industry data in Chapter IV; and
- Test hypotheses using the developed evolutionary model and make recommendations for construction contractors.

Using evolutionary approach, the current study considers contractors as individual entities competing with each other for common job opportunities in a construction market. Considering that contractors may have different risk attitudes and that risk attitude is a universal trait, it is hypothesized that individual contractors' different perceptions of risk and resulting different risk-taking behaviors in competition could affect competition among themselves and their own performances. The current study also takes multiple perspectives from the individual levels to the aggregate levels for the population of contractors. And, success of a contractor is analyzed within the domain of competition for the long-term.

Conventionally, different risk attitudes have been represented using expected utility theory. However, the theory and the method are not easy for practitioners to understand and it is also difficult to construct utility functions for individual contractors. It has been 60 years since the concept was introduced and few practitioners have learned it yet. There are few studies that measured risk attitudes for a large sample of

contractors. Consequently, the effect of risk attitude on competition has not been studied for construction contractors.

The proposed new representation method uses the concept of Value at Risk that is easy for practitioners to understand and apply to real business decisions. Value at Risk measures the expected value of loss in a simple manner by combining the effects of undesirable results such as cost overrun and probabilities that the undesirable results occur. For the new method, a new term, *maximum loss allowance* is introduced. It is defined as the maximum amount of loss that an individual firm can allow for a job. Using different amounts of MLA denominated in dollars, contractors' different risk attitudes are simply and quantitatively expressed. Risk-tolerant contractors allow risks of losses to obtain potentially large profits, so they have large amounts of MLA. Risk-averse contractors do not allow possibly large losses, so they have small amounts of MLA. VaR and MLA have the same metric, dollars. Based on the comparison of these two measures, contractors' go/no-go decisions can be easily described.

Five hypotheses were developed for the investigation of the effects of risk attitude on contractors' competitive success in construction. The hypothesized effects by different risk attitudes are about the differentiations of performance among contractors (winners vs. losers) in a market. The differentiations are expected to be observed in their profitability, survival, growth, and diversification level. Moderately risk-averse contractors would make trade-offs between the two extreme risk attitudes (most risk-tolerant and most risk-averse) better than moderately risk-tolerant contractors

that could suffer large losses. The developed hypotheses anticipate outperformance of moderate risk-aversion in the construction market.

CHAPTER VI

AN EVOLUTIONARY SIMULATION MODEL

6.1 Development of an Evolutionary Model

The current study develops an evolutionary simulation model in which contractors compete with each other in the competitive bidding environment. The main purpose of the model is to investigate how contractors' risk attitudes affect the competition among them, their performances, and the structure of the industry itself by tracking individual behaviors that depend on their own risk attitude and their performances and by measuring aggregate patterns that evolve at the population level.

Comprehensive competition studies are complex because this type of study needs to consider multiple aspects such as how individuals behave in their competition and what results through the competition at the individual level as well as at the aggregate population level. Simulation is one of the most advantageous methods to analyze competition in which individual behaviors need to be considered, due to the complexity of the solutions (Sounderpandian, 2007). Since it is impossible to test contractors' competition in the real world and the absence of longitudinal data on individual firms, simulation is the only feasible approach for the current investigation.

6.1.1 *Uses of Empirical Findings*

A large longitudinal data set on multiple contractors' business activities over long time periods would be very helpful for the current investigation. However, there are few data available for such a longitudinal study in construction. Even if actual data were available, it would be not easy to analyze contractors' risk management, their risk attitudes, and competition among them since any historical data do not provide information about how contractors perceive risks and how they decide their risk-taking at the time of decision making. As found in Chapter III, many empirical studies on risk-return association and organizational performance found controversial results due to the limitations on the measurement of risk (*ex-ante* vs. *ex-post*) and the qualitative characteristics of organizational issues.

Despite a limited amount of data and short time span, the analysis of the construction industry data performed in Chapter IV provides valuable information. Even though the data themselves do not provide direct information about contractors' competition and their organizational risk attitudes, it is considered that the empirical findings from the industry data are resultants of competition among the contractors in the market place. That is, risk attitude of contractors can be inferred from the aggregate behavior of the industry. The patterns of interest include the size distribution of construction contractors, their diversification pattern, and the changes in the industry capacity by individuals' organizational expansions, contractions, deaths, and births, which are caused by competition.

6.1.2 *Population of Contractors in the Model*

The firm rank in the ENR data is based on 400 individual contractors' gross revenues every year. The contractors' gross revenues are results of competition with their competitors in the market. Of course, the competition invisible in the data occurs within a larger population than the 400 largest contractors. By year, some contractors are added to the list of top 400 firms thanks to better performance, i.e., increased gross revenues. Some successful and large firms stay on the list over many years. Meanwhile, others disappear from the list due to bad performance, i.e., decreased gross revenues. But, a disappearance from the list does not necessarily mean a firm death. Some firms keep entering into and exiting out of the list around the rank 400. These entrances and exits also relate to the competition among the contractors.

To take account of this scope of competition within the population, the population in the current model has 500 contractors in an assumed market. Initially, the 500 firms are located uniformly over the eight market sectors, i.e., 62 or 63 firms per market sector. The model measures performances of the contractors that are ranked between 1st and 400th for comparison with the empirical findings in the ENR data. Business failures are replaced by new firms so that the model keeps the total number of contractors at 500. In the model, the industry has eight market sectors as classified in the ENR data.

6.2 Description of the Model

This section provides detailed descriptions of the structure and the algorithms in the developed evolutionary simulation model. There are 500 competing contractors in the model to obtain construction jobs available in the market through competitive bidding. Individual firms' organizational changes (growth, contraction, death, and diversification) are based on the individuals' performances that are determined through competition in the market place. The evolutionary model represents these dynamics.

Figure 6.1 shows a simplified flow chart of the evolutionary simulation model.

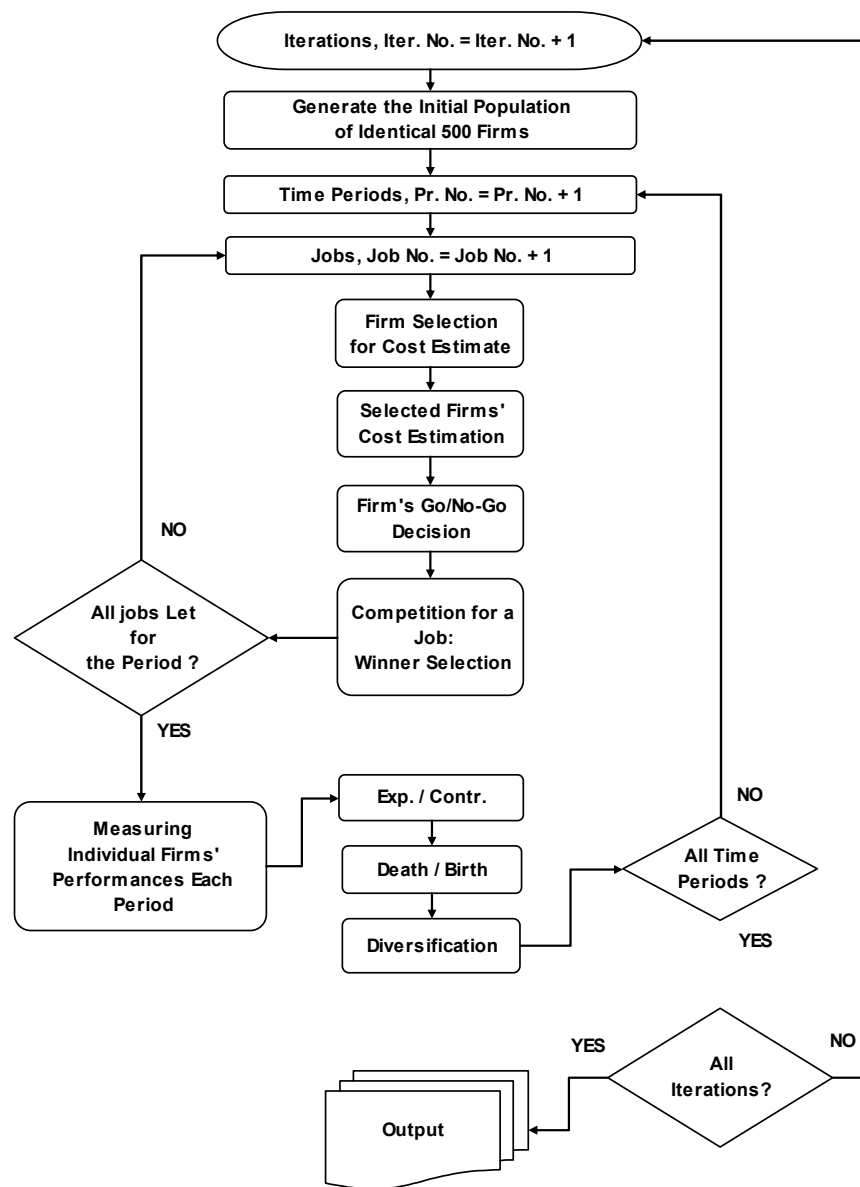


Figure 6.1 Flow Chart of the Evolutionary Model

To take the long-term perspective on the market competition and success of firms, the simulation runs for long periods (200 periods). These periods do not represent any specific times or years. They represent updates to the industry configuration, using a

number of periods necessary to achieve a steady state condition to be compared with the cross-sectional data for the industry, which were found in Chapter IV.

The stochastic simulation model takes account of the uncertainties that contractors face. The major uncertainties are represented in contractors' cost estimates and actual costs of jobs. The simulation runs for multiple iterations (200 iterations) to achieve convergence. Following are detailed descriptions of each component in the flow chart in Figure 6.1.

6.2.1 Initial Conditions and Differentiation by Risk Attitude

At the beginning of the simulation, the model generates an initial population of 500 firms. All firms are given identical conditions and characteristics, except for their own risk attitudes. The identical conditions for the contractors are their initial sizes (i.e., the same number of employees), estimation capability, productivity, overhead rate, initial wealth (cash reserve), and decision rules on corporate strategic behaviors (firm expansion, contraction, death, and diversification). Initially, each contractor has only one establishment in one market sector (its original sector). Each sector has the same number of contractors (firms). Individual firms may extend their business by growth in their original sectors or by diversification (opening new establishments in other sectors).

Risk attitude is considered as a universal and genetic characteristic of contractors. But, individuals may have different levels of risk attitude. By differentiating risk attitude among contractors but maintaining all the other conditions and characteristics

the same, the model isolates the effects of risk attitudes on contractors' competitive success.

Each firm's risk attitude is represented by a quantitative measure, MLA, which is the maximum amount of possible loss which a firm allows from a job. For example, a contractor's MLA can be 30% of the expected cost for a job. Then, its MLA will be 3M assuming \$10M to be the expected cost. Individual firms' MLAs (in dollars) are randomly drawn from a uniform distribution (which is the least informative of all distribution) at their founding as their own genetic feature. Different prior distributions other than the uniform distribution are tested in Chapter VII as a part of model validation.

Any vacancy due to firm deaths is filled by firm births to keep the total number of firms at 500. The random assignment of risk attitudes is applied to new firms at their founding in the same way using the same uniform distribution. For a diversified firm, its establishments inherit the parent firm's risk attitude.

6.2.2 Bid Opportunities and Selection of Bidders

The current model tracks all individual firms' risk-taking behaviors in bids. Each period, a constant market demand is assumed with the same number of jobs and the same size of jobs. All jobs are assumed to be identical to focus on the effects of risk attitude. The amount of available jobs is equal for all of the classified sectors.

For each job under bid, a fixed number of firms, assumed to be 6 in the model, are randomly selected. Initially, all firms have the same capacity (represented by the same number of employees). Therefore, all firms have same random chance to be

selected to be a bidder. While competing with other firms and performing jobs, individual firms may expand or contract depending on their monetary performance over multiple periods. Some firms with profits would expand while others with losses would contract in size. Then, the initially identical firms become heterogeneous in their size over periods.

Thus, the random selection of firms for bids takes account of this variability in individual firms' capacity. The model represents the general relationship between the size of a firm and the number of jobs that the firm pursues: large firms look for more jobs than small firms. In a real market, the amount of jobs that a firm can perform is limited by the firms' bonding capacity. A firm's bonding capacity would be proportional to the size of the firm, which is represented by the firm's employment size in the current model. To represent the variable firm sizes, the model defines the relative size of individual firms' capacity in the total industry capacity. Individual firms' relative sizes are defined using Equation 6.1.

$$\begin{aligned} \text{Total industry capacity} &= \sum_{i=1}^n \text{firm}_i \text{ capacity} \\ \text{Relative size of capacity of firm}_i &= \frac{\text{capacity of firm}_i}{\text{Total industry capacity}} \quad [6.1] \\ i &= \text{firm's index } (1 \leq i \leq 500) \end{aligned}$$

The actual selection process in the model is explained below. Each firm's relative size is measured using Equation 6.1 each period since the firms' size may vary. Their relative sizes change over periods by the individual firm's expansion or

contraction, as well as by deaths and new entrants. The decision rules for individual firms' capacity changes are discussed in later sections.

Note that the total sum of the firms' relative sizes is always 1.0. Then, the individual firms' relative measures can be placed on a horizontal line shown in Figure 6.2, a graphical representation of the total industry capacity. Each firm is given its own range. Larger firms have wider ranges than smaller firms. For the selection of bidders, a number is randomly drawn from a uniform distribution $[0.0, 1.0]$. A firm that has its range in which the random number lies is selected for cost estimates. Firms are randomly selected but the selection is correlated to their relative sizes, so that larger firms bid more often than smaller firms. The process continues to select firms to have the fixed number of bidders for each job. Of course, this selection algorithm avoids the case that any firm is selected more than once.

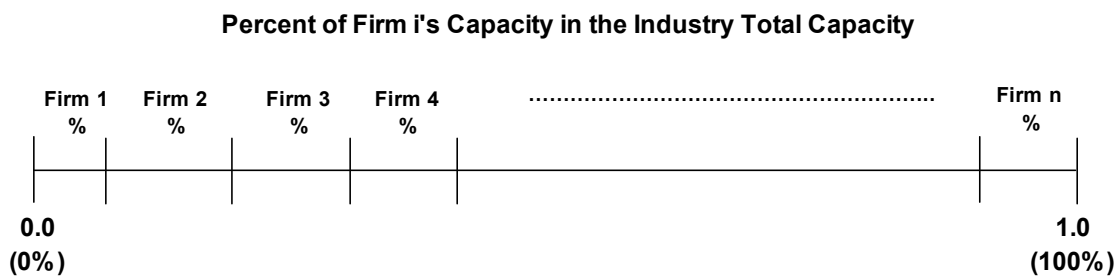


Figure 6.2 Composition of Firms in the Industry Based on Their Relative Sizes

6.2.3 Contractors' Cost Estimates and Go/No-go Decisions

For each job, a fixed number of contractors are chosen based on the selection process discussed above. However, the actual number of final bidders for each job may

vary depending on contractors' go/no-go decision making. This section discusses individual firms' cost estimates and their go/no-go decisions in the model.

Cost Estimates

In the real market, jobs are different in size, complexity, etc. However, in the current model, all jobs are assumed to be identical in every aspect, except for their actual costs. Contractors may have different cost estimates for an identical job. According to Seydel (1994), there are three basic reasons for the variation in competitor behaviors in bidding situations:

- Variation in costs among competitors;
- Variation in markup level among firms due to different strategies; and
- Difference in projects with respect to desirability, risk involved, and complexity.

The current model represents the variation among contractors' estimates and uncertainties in actual costs. As assumed in the initial conditions, all firms have the same estimating capability. However, individual firms' estimates have stochastic characteristics due to estimation errors, estimator's bias, omissions, etc. To represent the variation, firms' cost estimates are randomly drawn from the same distribution

$$N(\mu_e, \sigma_e^2).$$

The model does not represent the variation in markup level among firms. The variation could be due to individual firms' different strategies or different internal conditions. However, the model does not differentiate firms' specific strategies. The specification of individuals' strategies requires additional assumptions and makes the

model more complex. To isolate the effects of risk attitude, the same fixed percentage markup is assumed: all firms apply the same fixed markup percentage to their own cost estimates to decide the bid amount.

Go/No-go Decisions

Suppose there are only two bidders (contractors *A* and *B*) for a job and their estimates are different. To represent the variation of the cost estimates by the firms, a normal distribution $N(\mu_e, \sigma_e^2)$ is assumed as shown in Figure 6.3. Note that the two contractors have a same estimation capability and there exists variation in their estimates. The figure provides a comparison of cost estimates by the two contractors and corresponding VaR based on their cost estimates. Contractor *A* has a cost estimate greater than μ_e while contractor *B* has its estimate smaller than μ_e . So, contractor *B*'s VaR is greater than contractor *A*'s. However, it does not indicate that contractor *B* would not bid and contractor *A* would bid.

Contractors' go/no-go decision does not solely depend on the amount of VaR, the expected value of possible losses. Their decisions depend on their own risk attitudes, which lead to different perceptions of risk or possible loss from a job. If contractor *B* has its MLA greater than the VaR associated with its cost estimate, contractor *B* will bid. If contractor *A* has its MLA smaller than the amount of the current VaR associated with its cost estimate, contractor *A* will not bid. Depending on the amounts of MLA that represent the contractors' risk attitude, their decisions may vary.

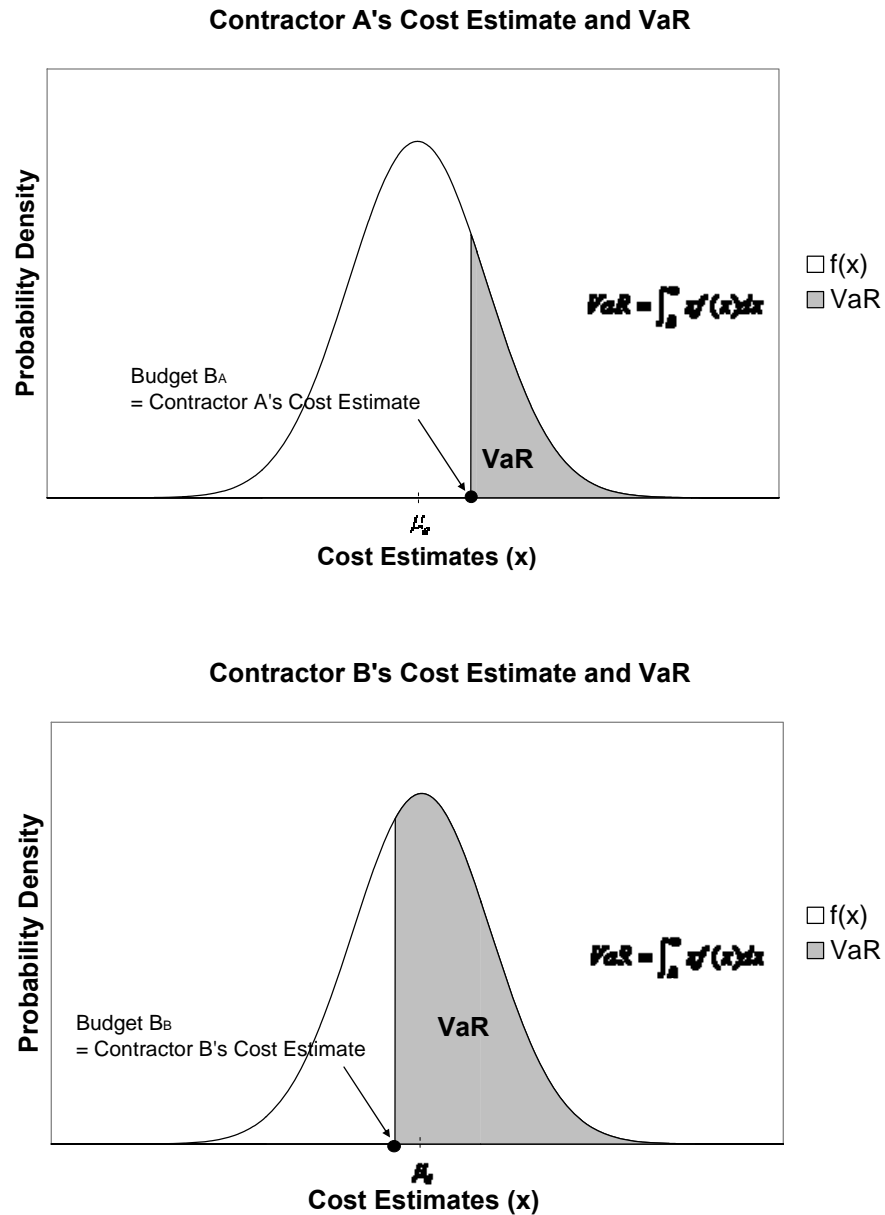


Figure 6.3 Comparison of Two Contractors' Cost Estimates and VaRs

Due to contractors' go/no-go decisions, the number of final bidders varies even though a fixed number of firms are selected for each job. To keep a minimum level of

competition in the market, the minimum number of final bidders in the model is set at two.

6.2.4 *Competition and Actual Costs*

Competitive bidding for lump sum contracts is the major competition mechanism in the current model. Bidders do not know actual costs when they bid for a job. When a contractor wins a job, the fixed price contract for the job is the risk transfer from the owner to the contractor. In the model, actual costs are randomly drawn from a normal distribution $N(\mu_c, \sigma_c^2)$ to represent the uncertainties inherent in the construction business.

When a contractor bids for a job, it incurs a bidding cost. Frequent bidding without obtaining jobs will cause an unfavorable effect on firms' monetary performance. Therefore, there will be effects on individual firms' performance with respect to bidding costs, the bid frequencies, the probability of winning, and the average profitability from jobs. Competition occurs for each job among multiple contractors that estimate job costs and make go/no-go decisions depending on their own risk attitude. The flow chart in Figure 6.4 describes the competition among contractors for each job.

As shown in Figure 6.4, contractors spend general overhead expenditures regardless of their go/no-go decisions. Final bidders spend bidding costs and the winner, the lowest bidder, earns a profit or loss depending on the actual cost of the job. Each of individual contractor's monetary performance is measured over all jobs and summarized

at the end of each period for their decisions on expansion, contraction, or death, which are described in detail in the next sections.

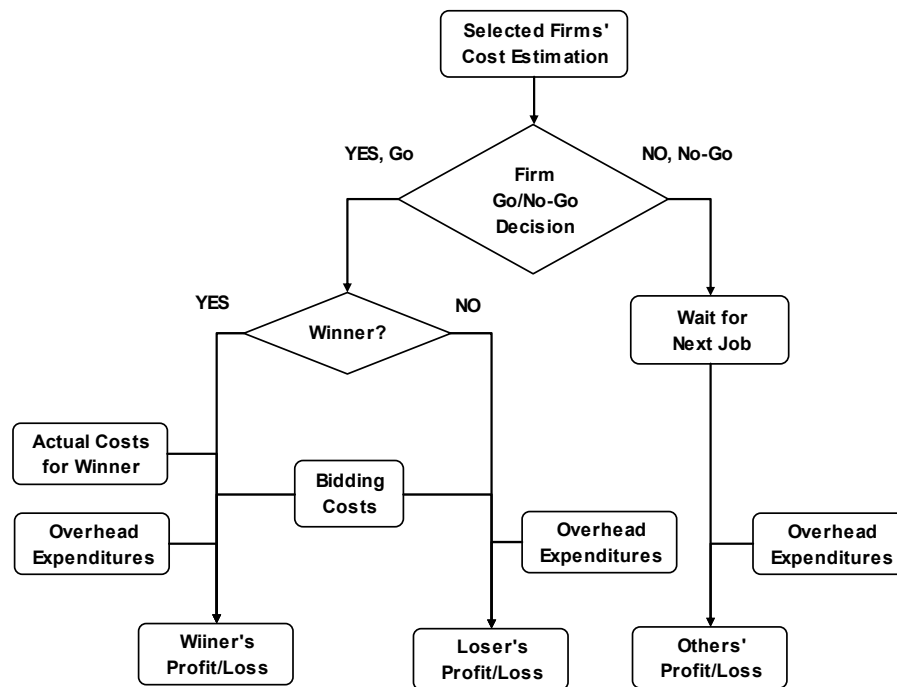


Figure 6.4 Flow Chart – Competition

6.2.5 Decision Rules for Contractors' Strategic Behaviors

At the end of each period, firms may expand, contract, go out of business, or diversify into new sectors depending on each individual firm's performance and financial condition. All business failures are replaced by new firms to keep the total number of firms constant at 500. New firms have the identical initial conditions that the firms in the initial population. New firms compete with existing firms to obtain jobs through competitive bidding and they also may expand, contract, or go out of business.

Rules of the individuals' behavior in an evolutionary model should be plausible and simple (Metcalf and Foster, 2004). Following are the basic decision rules of the contractors' strategic behaviors. The parameters in the following descriptions are determined by fitting the model outputs to the industry patterns found in the actual data.

Decision Rules on Establishment Expansion and Contraction

Organizational expansions and contractions occur at the establishment level at the end of each period depending on the performance of individual establishments. The rule is simple: an establishment expands when it obtains a profit and contracts when it suffers a loss. In general, contractors desire to grow in a market but they are not willing to shrink in size (Kim, 2004). Sometimes, they are too optimistic about the market.

In the model, contraction of an establishment is restricted by random chances, $a\%$ (less than 100%) in order to represent the contractors' reluctance to contract in size, while expansion of an establishment occurs whenever the establishment obtains a profit.

- Probability of expansions with profits: 100%
- Probability of contractions with losses: $a\% < 100\%$

For each establishment, the size of expansion or contraction is determined in proportion by b (in Equations 6.2 through 6.5) to the amounts of profit/loss at the establishment level. Large profits increase the size of expansions while large losses increase the size of contractions. Also, the size of expansions and contractions may be related to parent firm's financial condition, i.e., cash reserves. For example, the size of

expansions at an establishment could be greater when it obtained a profit and its parent firm is in a better financial shape.

For an establishment in the model, with the probabilities of expansions and contractions discussed above, if its parent firm has cash reserves more than the parent firm's overhead, the establishment expands more (by $c > 1.0$) if it earned a profit, meanwhile the establishment contracts by normal size (without adjustment, ie., $c = 1.0$) when it earned a loss. On the other hand, the size of contraction at an establishment would be greater when its parent firm is in a bad financial shape. For an establishment, if its parent firm has cash reserves lower than the firm's overhead, the establishment contracts more (by $c > 1.0$) if it earned a loss, meanwhile the establishment expands by normal size (without adjustment, i.e., $c = 1.0$) when it earned a profit.

Based on these general concepts, size of an expansion at the establishment level is decided as below when an establishment earned a profit:

- If a firm has cash reserve greater than its overall overhead:

$$b (\text{employees}/\$M) \times \text{the amount of profit } (\$M) \times c \quad [6.2]$$

- If parent firm has cash reserve smaller than its overall overhead:

$$b (\text{employees}/\$M) \times \text{the amount of profit } (\$M) \times 1.0 \quad [6.3]$$

Size of a contraction with the probability of contraction a at the establishment level is decided as below when an establishment earned a loss:

- If a firm has cash reserve greater than its overall overhead:

$$b (\text{employees}/\$M) \times \text{the amount of profit } (\$M) \times 1.0 \quad [6.4]$$

- If a firm has cash reserve smaller than its overall overhead:

$$b \text{ (employees/\$M)} \times \text{the amount of profit (\$M)} \times c \quad [6.5]$$

Decision Rules on Establishment/Firm Death

When a firm fails to maintain its cash reserves above zero, the firm closes its establishments that produce losses. In this decision, a parent firm and all its establishments may go out of business if all of the firm's establishments suffer losses. A death decision can be made at the establishment level. Even though a parent firm has positive cash reserves, the parent firm may want to close its establishment(s) if an establishment suffers a large amount of loss, e.g., larger than (d) times its annual overhead (establishment overhead) as in Equation 6.6 below. So, a death decision at the establishment level can be defined as:

$$\text{Establishment death, if profit} < -(d) \times \text{annual overhead} \quad [6.6]$$

Whenever there is a firm death, a new firm enters into the market so that the total number of firms is maintained constant (500). A new firm has only one establishment at its founding. The birth occurs in the same market sector in which a firm death occurred. If successful in competition, the new firm will grow and diversify by opening establishments. Otherwise, it will suffer loss and may go out of business.

Decision Rules on Market Diversification

There have been few studies about contractors' diversification and general rules for contractors' market diversification is not available in the literature. Nevertheless, in general, contractors would diversify if they have earned profits and built financial resources enough to open a new establishment in a new sector. Using this general concept, contractors' market diversification is represented in the current model.

In the model, initially every firm has only one establishment in the model. Individual firms may come to have more than one establishment by diversification. A firm may open one new establishment when it has cash reserve greater than ($e\%$) of its overall overhead. However, the frequency of diversification is restricted by random chances, ($f\%$), since it can be reasonably assumed that having enough cash does not always lead to a contractor's diversification. Different contractors could have their own diversification strategies in a real market. However, specification of their different strategies would make the model unnecessarily more complicated and would require additional variables and assumptions.

Different methods are found in economic models to represent the size distribution of entrants to a market. Hannan et al. (1990) used an approximately lognormal distribution skewed to the right (larger sizes) to determine the random size of each entrant. Kwaśnicki (1998) simply assumed the initial market share of an entrant is not larger than 0.5%. And, Nelson and Winter (1982) used a uniform distribution with a range of relatively smaller values than existing firms to decide the size of entrants. In the current model, the minimum size of a new establishment is assumed to be 100

employees and the sizes of new establishments are assumed to be exponentially distributed (skewed to the right) with the mean value (h in Equation 6.7).

In addition, the size of new establishments is proportional (by g in Equation 6.7) to firm cash reserve since financially strong firms can open large establishments. For the contractors' market diversification, the current model decides the size of new establishments using Equation 6.7:

$$\begin{aligned} &\text{Size of new establishment (number of employees)} \\ &= \text{Exp}(h) \times \text{CR}(\$M) \times g(1/\$M) + 100 \end{aligned} \quad [6.7]$$

Where, $\text{Exp}(h)$ is a random variable from an exponential distribution whose mean is assumed to be (h) and CR is parent firm's cash reserve.

All 500 firms in the model follow these simple rules discussed above for their strategic behavior: expansion, contraction, death, and market diversification. There are eight model parameters ($a \sim h$) to be specified. The value of each parameter has been decided by fitting the model behaviors to the industry patterns found in the actual U.S. construction industry data analyzed in Chapter IV. The determined parameter values for the contractors' strategic behaviors are presented in Section 6.3.

Compared to the complexity in contractors' strategic behavior in the real market competition, the number of parameters in the current model is kept very small. The simplicity of these behavior rules eliminates unnecessary factors in the competitive system and helps the current study focus on the main issue, the effects of firms' risk

attitude on competition. The model does not attempt to replicate the complexity of the real world or the behavior of specific contractors; hence the model does not specify any complicated model parameters such as level of competitiveness (Dosi et al., 1995), stochastic functions for growth rate (Gibrat (1931); Simon and Bonini (1958)), acquisition of jobs by means other than fixed price contracts and winner-take-all bidding, functions of production (Jovanovic (1982); Kwaśnicki (1998)), founding and mortality rates (Hannan et al., 1990), etc which are frequently observed in such economic models.

6.2.6 *Firm Performance*

Performances are measured individually for each of the firms and their establishments. The only difference among model firms lies in their own risk attitudes that affect their go/no-go decision in competitive bidding. The model tracks the firms' performances differentiated through competition.

The firms obtain jobs and are paid based on the contract price which was decided when the job was awarded. If the actual cost of a job is greater than the contract price, the contractor faces a loss, and *vice versa*. Firms pay their overhead expenditures which are proportional to their own capacity size (the number of employees). When a firm grows or diversifies, its overhead burden increases, and *vice versa*. The overhead rate to firm capacity is estimated using the actual U.S. construction industry data in Section 6.3.

In the model, profits/losses from jobs, bidding costs, and overhead expenditures are measured for each of the establishments. And, the profits for establishments accumulate in their parent firms' cash reserves. Cumulative profits and cash reserves are

indicative of contractors' economic performance. Contractors' growth and diversification level are also measured by their employment sizes and gross revenues in the multiple market sectors. Also, age is a measure of firm performance indicating the firm's survival. Ages are counted in periods as long as a firm maintains its business with more than one establishment in a market sector.

6.3 Model Parameters

There are other factors that could affect construction contractors' competitive success in a market. They include tangible and intangible factors such as financial strength, organizational structure, experience, better management, relationship with clients, intelligence, different market strategies, etc. For each of these factors, feasible values or measures among individual contractors would differ. However, in order to identify the effects of contractors' risk attitude, the current study assumes that these possible factors or organizational characteristics are similar for every contractor. Thus, values of the model parameters in the model are determined to represent overall averages.

The current model aims at reproducing aggregate patterns that are derived from the real U.S. construction industry data. Model parameters have been fitted to reproduce the empirical findings. The following sections discuss the major model parameters. Summaries of the model parameters and their values are provided in Tables 6.5 and 6.6.

6.3.1 Cost Estimate and Markup

Contractors estimate the cost of jobs and add their markup to decide their bid amounts. Critical errors in cost estimates could result in significant losses (in case of underestimates) or reduced market share (in case of overestimates). Construction cost estimation is an experience-based process which is affected by people's competence and experience and there is no generally accepted method (Hegazy and Moselhi, 1995).

To figure out the current practices in cost estimation for bid preparation, Hegazy and Moselhi (1995) performed a questionnaire survey. Survey responses were collected from 78 large general contractors in the U.S. and Canada. Most of the surveyed contractors have most of their business in the building construction market. Their survey results provide descriptions about the differences in contractors' cost estimates.

Contractors have different definitions of markup. Markup is usually defined as an amount added to the cost estimate to provide a contribution to the contractor's general overhead and profit and to cover any contingencies that arise in the job (Benjamin, 1969). However, Hegazy and Moselhi (1995) found that contractors consider the application of markup differently as shown in Table 6.1.

Table 6.1 Coverage of Markup

Coverage of Markup	Percentage of Respondents
profit only	44%
profit + contingency	33%
profit + general overhead	17%
profit + general overhead + contingency	4%
profit + general overhead + project overhead + contingency	3%

Also, Hegazy and Moselhi (1995) found that the contractors have divergent ways to estimate general overhead (e.g., head office expenses) as summarized in Table 6.2. Most of the contractors perform detailed estimates for direct costs, but they do not have a commonly accepted method for overhead estimation.

Table 6.2 Estimation of General Overhead

Estimation of General Overhead	Percentage of Respondents
% of direct costs	31%
% of the sum of direct costs and project overhead	27%
Not estimated	19%
Detailed estimate	18%
% of project overhead	5%

Based on the results of the survey, Hegazy and Moselhi (1995) derived the approximation about relative contribution of cost elements as the percent of the total bid amount: direct cost: 80~90%; project overhead: 10~30%; general overhead: 5~15%; and markup: 0~10%. The approximation does not make the total 100%. In their approximation, project overhead, general overhead, and markup are differentiated. If the markup is assumed to cover contingency, project overhead, and general overhead, as by some contractors in Table 6.1, the contribution of markup would be much greater.

For the current model, contractors' cost estimates are randomly drawn from an identical probability distribution while their percentage markups are assumed to be identical (a fixed percentage of the cost estimate). Therefore, it assumes that contractors' estimates may be different due to variation associated with omissions, errors, or over- or under-estimates, which are represented by random draws while all

contractors have a same level of estimation capability. So, the random draws are made from an identical probability distribution. In the model, contractors' direct cost estimates follow $N(\mu_e, \sigma_e^2)$, $\mu_e = \$10\text{M}$ and $\sigma_e = \$1.5\text{M}$. The distribution is truncated with the minimum cost estimate set at \$5.5M.

6.3.2 *Actual Costs of Job*

Cost overruns and schedule delays are common in the construction business (Frimpong et al., 2003). Skewness in the distribution of actual construction project costs is supported in the literature (Benjamin, 1969): it is usually assumed that the probability distribution of the ratio of actual as-built cost to the original cost estimate has a longer tail (skewed to the right) while a shorter tail at the other side. Schedule delays that may result in cost overruns are also a frequently cited problem in the construction business.

There have been many studies on the issues. Kaming et al. (1997) identified factors affecting project performance in terms of time and costs for high-rise construction projects in Indonesia. The factors include inflation, inaccurate estimating, complexity of work, change orders, low labor productivity, etc. Akinci and Fischer (1998) identified factors affecting cost estimates and the final cost of a project, especially uncontrollable risk sources. Odeck (2004) found a pattern of discrepancy, the mean of 7.9% ranging from -59% to 183%, between estimated and actual costs from Norwegian road construction projects. Also, Lee (2008) found the majority of road and rail projects in South Korea (total 161 completed projects) similarly experienced significant cost overruns.

Whatever the reasons for the discrepancies between estimated and actual costs are, the phenomena of cost and schedule overruns are prevalent in the construction business. To represent these phenomena, the actual cost of a job is represented as a random variable drawn from a truncated normal distribution with the minimum value in the area of the left side. In the current model, actual costs of job are assumed to follow $N(\mu_c, \sigma_c^2)$, $\mu_c = \$10\text{M}$ and $\sigma_c = \$2.3\text{M}$, and the minimum actual cost is \$5.5M.

6.3.3 Overhead Rate

The Construction Financial Management Association (CFMA) publishes the results of their survey about construction firms' business every year. Table 6.3 shows the collected financial data from the CFMA publication on the contractors' *Selling, General and Administrative Expenses*. General expenditures (i.e., overhead) are presented as a percent of total revenues. Contractors classified by type of jobs show different levels of overhead percentages. Industrial and nonresidential contractors have a lower average percentage than heavy and highway contractors. The average of the overhead percentages for all construction contractors in their survey is about 6.7%.

Table 6.3 Selling, General and Administrative Expenses (% of Total Revenues)

<i>Composite Firms</i>	<i>1996</i>	<i>1997</i>	<i>1998</i>	<i>2000</i>	<i>2002</i>	<i>Average</i>
<i>All Companies</i>	6.2%	8.9%	5.7%	6.2%	6.4%	6.68%
<i>Industrial & Nonresidential Companies</i>	4.3%	4.7%	3.8%	3.8%	4.5%	4.22%
<i>Heavy & Highway Companies</i>	7.5%	6.5%	6.6%	8.0%	6.2%	6.96%

In the current model, *overhead rate* is defined as the ratio of general overhead to the employment size of a business organization as in Equation 6.8. The rate is different from the common representation of overhead, a percent of total revenues as in the CFMA financial data. The assumption is that organizations having large numbers of employees spend more as general overhead, *and vice versa*. It considers the existence of fixed costs in firm business operations.

$$\text{Overhead Rate} = \text{Overhead Expenditures}(\$) / \text{Employee} \quad [6.8]$$

Individual contractors in the model expand and contract in size depending on their performance. However, an expansion or contraction may not necessarily mean an increase or decrease in firm gross revenues. A contractor that expanded its capacity based on profits earned in the previous period $t-1$ could face overhead burden in the current period t if the contractor does not obtain more jobs to use the expanded capacity. Thus, an overconfident expansion could result in critical failure as discussed in Chapter III regarding contractors' business failure.

Two statistical data sets by the U.S. Census Bureau, 1992 Enterprise Statistics and 2002 Economic Census, are used to estimate the overhead rate (\$million/employee) for the current study. These data provide the number of employees and the amount of total revenues for firms in each size class, but not the amount of general overhead expenditures. The general overhead expenditures are estimated assuming that the

average percent of general overhead in total gross revenue would be about 6.7% as found in Table 6.3.

The data in Table 6.4 show the estimated revenue rate (gross revenues per employee) and overhead rate (overhead expenditures per employee) for large contractors having more than 500 employees. The revenue rate varies from 0.152 to 0.278. The overhead rate varies from 0.011 to 0.019. For the current model, contractors' overhead rate is assumed to be 0.014 to fit the model outputs to the actual industry patterns.

Table 6.4 Overhead Expenditures (\$Millions) per Employee

<i>Data Sources</i>	<i>Sectors</i>	<i>Revenue Rate (\$Millions/employee)</i>	<i>Overhead Rate (\$Millions/employee)</i>
<i>1992 Enterprise Statistics</i>	<i>All Contractors</i>	<i>0.162</i>	<i>0.011</i>
	<i>General Building Contractors</i>	<i>0.278</i>	<i>0.019</i>
	<i>Heavy Contractors</i>	<i>0.152</i>	<i>0.011</i>
<i>2002 Economic Census</i>	<i>Commercial Building Contractors</i>	<i>0.241 (Average)</i>	<i>0.016 (Average)</i>
	<i>Housing Operatives</i>		
	<i>Industrial Building Contractors</i>		
	<i>Power Communication Contractors</i>		

6.3.4 Values of Model Parameters

The model has been developed using programming language C with Microsoft Visual Studio. Through the simulations, values of model parameters were determined. The determined baseline parameters are the best combination that enables the model to produce aggregate patterns fitted to the empirical findings from the actual U.S. construction industry data. Table 6.5 provides a summary of model parameters for

competitive bidding in the market. And, Table 6.6 provides another summary of model parameters for the contractors' strategic behaviors.

The aggregate patterns found in the model using the listed parameter values in Tables 6.5 and 6.6 are compared with the actual industry patterns found from the real U.S. construction industry data in Chapter VII. Also, all hypothesis tests performed in Chapter VII are based on the same parameter values.

Table 6.5 Model Parameters for Firms and Competitive Bidding in the Market

<i>Parameters</i>	<i>Value</i>
<i>Number of sectors</i>	<i>8 sectors</i>
<i>Number of jobs per period</i>	<i>1,800 jobs in each sector (Total 14,400 jobs in the eight sectors)</i>
<i>Mean of project cost</i>	<i>\$10M (= Mean of cost estimate)</i>
<i>Contractors' cost estimates</i>	<i>$N(\mu, \sigma^2)$, $\mu = \\$10M$, $\sigma = \\$1.5M$</i>
	<i>Minimum cost estimate: \$5.5M</i>
<i>Actual costs</i>	<i>$N(\mu, \sigma^2)$, $\mu = \\$10M$, $\sigma = \\$2.3M$</i>
	<i>Minimum actual cost: \$5.5M</i>
<i>Contractors' fixed markup</i>	<i>22% of firm cost estimate</i>
<i>Bidding cost per bid</i>	<i>\$50K per bid</i>
<i>Overhead expenditures</i>	<i>$0.014 \times \text{the employment size}$</i>
<i>Firm initial conditions</i>	<i>Initial size of capacity: 250 employees Initial cash reserve: \$5M</i>
<i>Random assignment of individual contractors' risk attitude</i>	<i>Uniform (\$2.2M, \$9.6M) - Min. 22% of the cost mean indicating the most risk-averse - Max. 96% of the cost mean indicating the most risk-tolerant</i>
<i>Number of firms selected for bid</i>	<i>6 firms</i>
	<i>Minimum number of final bidders: 2 bidders</i>

Table 6.6 Model Parameters for Contractors' Strategic Behaviors

<i>Parameters</i>	<i>Value</i>
<i>Establishment expansion/contraction</i>	<ul style="list-style-type: none"> - Probability of expansion with profit: 100% - Probability of contraction with loss: $a = 70\%$ - Expansion/contraction size multiplier: $b = 20.0$ - Proportional factor to firm cash reserve: $c = 2.0$
<i>Condition of establishment/firm death</i>	- Firm: cash reserve $< \$0$
	<ul style="list-style-type: none"> - Establishment death condition: If establishment profit $< -1.5 (d) \times$ establishment overhead
<i>Condition of diversification</i>	<ul style="list-style-type: none"> - If firm cash reserve $> 25\% (e)$ of firm overhead - Restriction by random chance: $f = 30\%$
<i>Size of new establishment size in diversification</i>	<ul style="list-style-type: none"> - Exponential random and proportional to firm cash reserve - Proportional factor to firm cash reserve: $g = 0.05$ - Mean of the exponential distribution: $h = 200$

6.4 Summary

Chapter VI discussed the structure and the algorithms in the evolutionary simulation model in which competition among multiple contractors is simulated and analyzed. Competitive bidding is described as the major mechanism of competition of the contractors that are all identical except their organizational risk attitude. The following major characteristics of the model have been discussed:

- Population of contractors in the model;
- Identical initial conditions and differentiation of contractors' risk attitude;
- Bid opportunities in the market and bidder selection for each job;
- Contractors' cost estimates and go/no-go decisions;
- Representation of uncertainties in actual costs of job; and

- Decision rules of contractors' strategic behavior.

In the model, all jobs in the market are identical, but actual costs of jobs are random, which represents uncertainties inherent in construction jobs. Depending on the winning bid and the actual cost, firms may obtain profit or loss from a job. Through competition, firms that are identical at the beginning of the simulation (in the initial population) become heterogeneous through competition in terms of size (capacity: employment size), age, profitability, cash reserve, diversification (the number of sectors where they have businesses), etc.

Individual contractors make go/no-go decisions for final bids depending on their own risk attitudes. Also, they make corporate strategic decisions on expansions, contractions, deaths, and market diversification. For these decisions, the developed evolutionary model uses general rules that are simple and plausible. Expansions and contractions occur at the establishment level while deaths may occur at the firm level as well as at the establishment level. Firm births occur to fill the vacancies due to firm deaths in order to keep the total number of firms constant. The rules of firm strategic behaviors govern all firms while their risk-taking behaviors in competitive bidding are dependent of their own risk attitudes.

Values of the model parameters were determined based on the available actual data and the plausible assumptions. The model behaviors were fitted to the actual industry patterns identified. In Chapter VII, the aggregate patterns in the model are compared with the actual industry patterns found in the real U.S. construction industry data.

CHAPTER VII

MODEL VALIDATION AND TEST OF HYPOTHESES

This chapter discusses validation of the model and results of the hypothesis tests. The aggregate patterns from the simulation results were fitted to the actual industry patterns identified in the U.S. construction industry data, which is a part of the model validation. First, the current chapter provides descriptions of the basic model behaviors and the fitted industry patterns based on the determined model parameters.

There is another issue that is validated for the evolutionary simulation model. A test is performed using the proposed new method using VaR to represent contractors' different risk attitudes and corresponding different risk-taking behaviors. A comparison of the two methods (the conventional method and the new method) is provided.

The five hypotheses developed in Chapter V are tested using the evolutionary simulation model to investigate the effects of risk attitude on contractors' competitive success. In addition, sensitivity analyses are performed to clarify the validity of the simulation results. Three major initial assumptions and conditions in the model are tested:

- Different assumptions on contractors' risk attitude: the current model considers heterogeneity in risk attitude among contractors. Two different assumptions are tested: *no risk-aversion* and *all risk-neutral* for contractors.
- Different prior distributions for random assignment of contractors' risk attitude.

- Different initial sizes of firms.

The simulation results are based on the parameter values summarized in Tables 6.5 and 6.6 in Chapter VI. The simulation is run until the system reaches a steady state, which is achieved when organizational responses to competitive selection forces become stable so that industry patterns such as size distribution and diversification pattern also become stabilized.

7.1 Model Behaviors vs. Actual Industry Data

In Chapter IV, three different types of industry patterns were identified as resultants of competition among contractors using the U.S. construction industry data. The identified patterns are: 1) size distribution of contractors in the market; 2) diversification pattern of large contractors; and 3) industry capacity changes by expansions, contractions, deaths, and births.

The developed evolutionary model produces aggregate industry patterns as the resultants of competition among multiple contractors. The following sections provide comparisons between the actual industry patterns and the aggregate patterns that evolved through competition in the model.

7.1.1 Size Distribution of Contractors

The size distribution of the model firms reaches a steady state over a number of iterations. Figure 7.1 shows the comparison between the actual size distribution of the ENR U.S. top 400 contractors and the size distribution of the 400 largest model firms. The distributions are very similar.

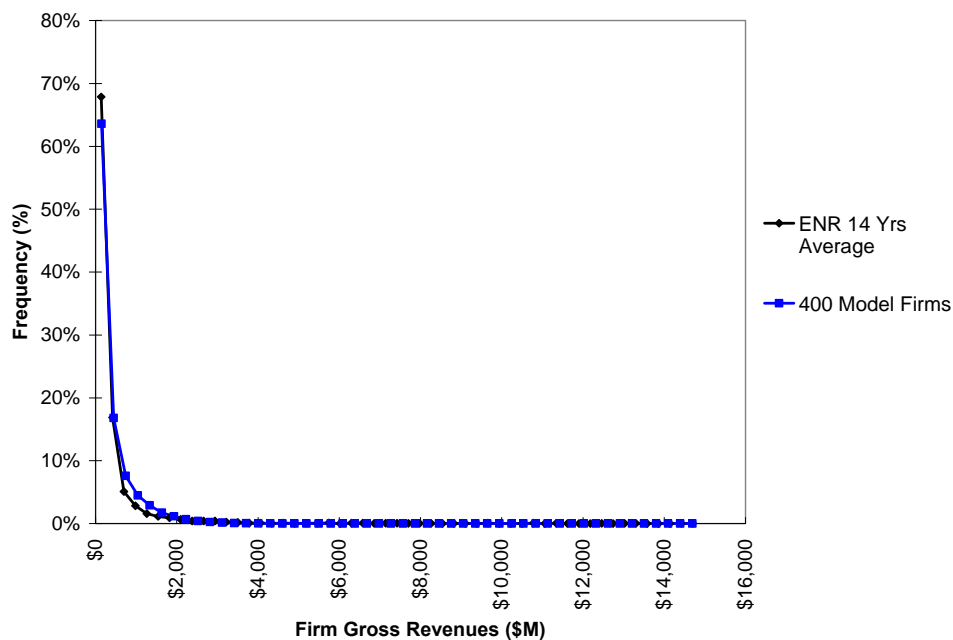


Figure 7.1 Size Distribution of Firms (Actual vs. Model)

Figure 7.2 shows the same comparison, but in the logarithm. Figure 7.2 shows inverse proportionality between the population density and firm size, indicating the existence of a power law. Considering that the firms in the model are differentiated only by their organizational risk attitudes, even though there are a lot of variables affecting

contractors' competition and their success in the real market, the similarity between the two distributions is significant.

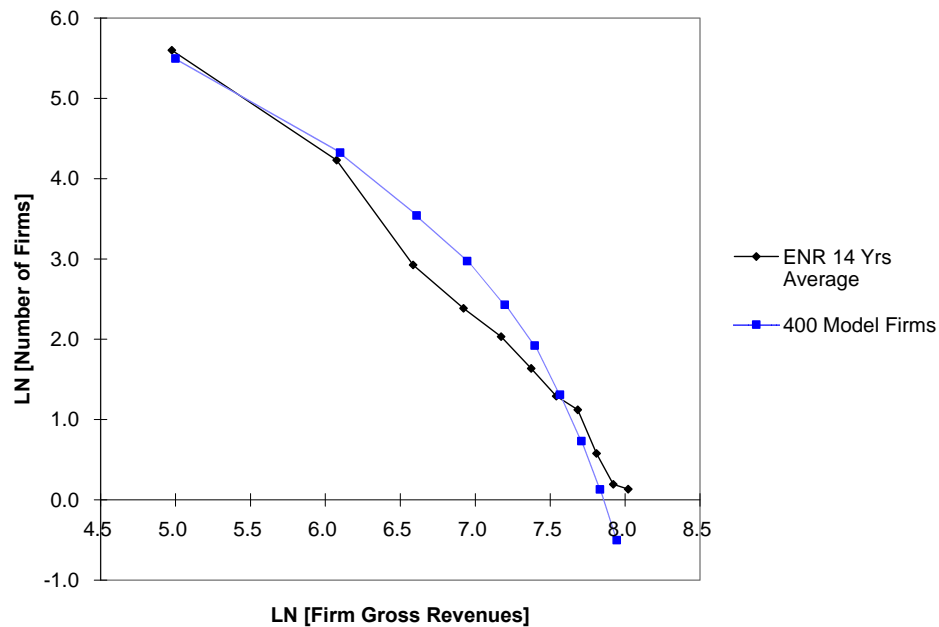


Figure 7.2 Size Distribution of Firms in the Logarithm (Actual vs. Model)

Note that the initial conditions of all model firms (initial size, overhead rate, and initial cash reserve) are identical. Contractors have the same level of variability in their cost estimates and they face the same level of uncertainties in actual costs. Also, the model parameters and the decision rules given for the model firms' business operation and strategic behaviors are identical. The differences in size among the model firms that develops the distribution in Figures 7.1 and 7.2 are caused only by their different risk-taking behaviors in competition, depending on their own risk attitudes.

7.1.2 Industry Capacity Changes

In Chapter IV, the Statistics of U.S. Business by the U.S. Census Bureau provide the employment changes by expansions, contractions, deaths, and births at the establishment level. These organizational changes in contractors' employment size are also results of competition in the market place. The model firms' employment changes are fitted to the actual industry data. For the comparison, the employment changes were measured at the establishment level in the model as in the SUSB data.

Table 7.1 shows the industry capacity changes (by percentage of the total industry capacity) that evolve through competition in the model in comparison with the Statistics of U.S. Business data. The percentage changes from the SUSB data in the table are 10 years' averages for a class of large contractors that have more than 500 employees, which represents the model firms. The simulation results are values averaged across the 200 iterations. The results are very close to the actual averages.

Table 7.1 Industry Capacity Changes

Type of Changes	Statistics of U.S. Business 10 Years' Average (1995 ~ 2004)	Simulation Results of 400 Model Firms
Expansions	13.9%	12.4%
Contractions	15.0%	13.8%
Births	4.9%	4.0%
Deaths	5.3%	5.5%
No Change	60.9%	64.3%

7.1.3 Diversification Pattern of Contractors

The last aggregate industry pattern to be compared is the diversification pattern of the contractors. Figure 7.3 provides the comparison between the diversification pattern of the 400 model firms and the actual industry pattern based on the ENR U.S. Top 400 Contractors data. The overall patterns are similar to each other but there are small differences between the two distributions, especially in the frequencies of firms that have lower diversity indices (0.1 and 0.2).

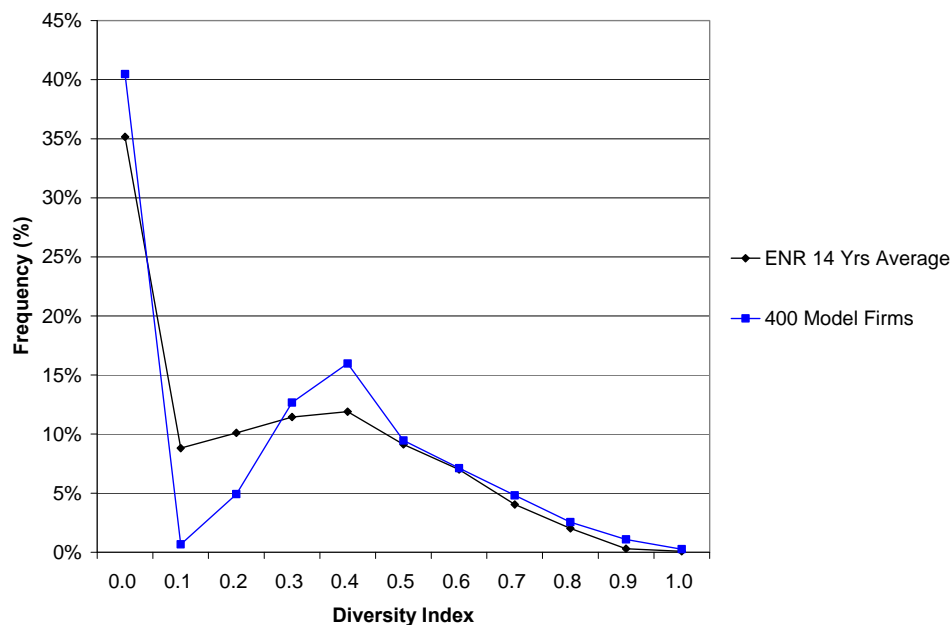


Figure 7.3 Distribution of Firms by Diversity Index

In the simulation model, it is assumed that all jobs in the market are identical. The identical size of jobs is \$10 million and the only difference among jobs is defined in actual costs. This assumption allows the current investigation to focus on the effects of

risk attitude on competition in the assumed market. However, every construction job is different in the real market. Usually, large firms exist to perform large jobs. But, a small establishment under a large parent firm could perform small jobs.

A sensitivity analysis using the model found that assuming smaller sizes for new establishments in the firms' market diversification together with smaller job sizes generates diversification patterns more similar to the actual pattern. The assumption enables the model firms to have very small portions of their gross revenues in their second or third market sector, which increases the frequency of firms that have lower diversity indices in Figure 7.3. Low values of diversity index such as 0.1 can be attained for a firm if the firm has the majority (almost 100%) of its gross revenues in one sector and very small percentages of its gross revenues in other sectors. Refer to the normalized diversity index in Figure 4.15 in Chapter IV to see how diversity index varies depending on different combinations of firm gross revenues in the assumed two market sectors.

However, the assumption of smaller sizes of establishments and jobs results in differences in other industry comparisons, for example, the model predicts more establishment deaths at their early ages than occur in reality. In the model, the bidder selection for each job is random, but it is based on the size of establishments. Therefore, in the model, very small establishments at their founding have difficulty in obtaining jobs. In the real market, very small establishments are able to obtain small jobs since large establishments usually do not perform the small jobs that the small establishments perform. That is, large construction firms often find it difficult to make a profit on small

jobs due to high fixed costs. This consideration is not included in the simulation model. Also, the model does not represent the distribution of jobs in size. The identical job size is kept to be \$10 million, which is consistent with the best combination of model parameters discussed in Section 6.3.4.

Another aggregate representation of diversity found in the actual data is the number of sectors per firm: how many sectors a firm operates its business in. Figure 7.4 shows the comparison between the actual pattern from the ENR U.S. Top 400 Contractors data and the simulation result. The two distributions are very similar to each other.

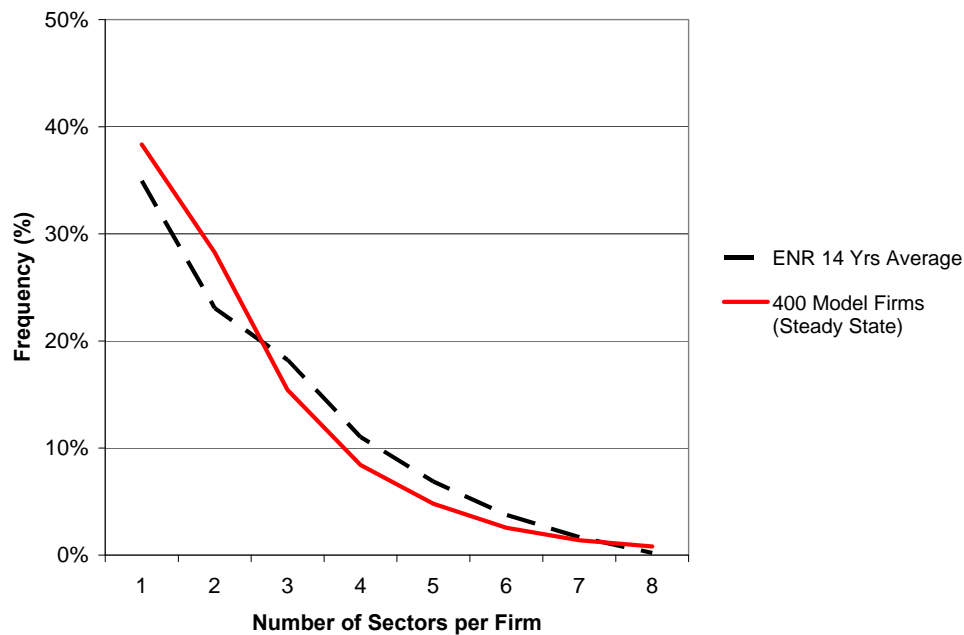


Figure 7.4 Number of Sectors per Firm

In the initial population, all model firms have only one establishment in one sector. Over simulation periods, these firms diversify into other sectors. The average number of market sectors per firm in the ENR US Top 400 Contractors is 2.5. The same average of the 400 model firms is about 2.3, which is the average from the distribution in Figure 7.4. It is clear from the figure that the diversity computed by the simulation is virtually identical to the ENR data.

7.1.4 Other Model Behaviors

This section provides other model behaviors that evolve through the simulated competition among contractors. The behaviors to be discussed are:

- Distribution of firms by age
- Diversity index - combination of multiple sectors
- Industry ratio: industry revenues to industry capacity

Age Distributions of Firms

Many studies in market ecology and economics have paid attention to mortality patterns of business organizations (Singh (1990); Ilmakunnas and Topi (1999)). The model generates a reasonable pattern that has been found in empirical studies. In general, there are a large number of young business organizations and a small number of old organizations in a market. Figure 7.5 shows the distribution of the 400 model firms by age over periods.

In the initial population, all model firms are new. Through competition in the market, successful firms survive and age while some of unsuccessful firms go out of business. Meanwhile, new entrants start their business and they are young. The age distribution of firms is also a result of competition in the market.

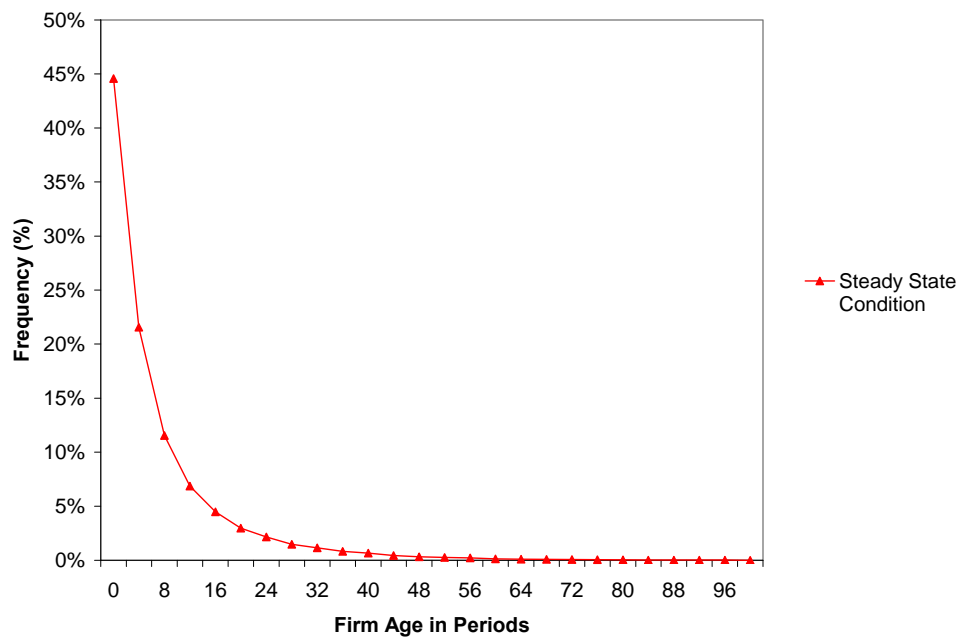


Figure 7.5 Age Distribution of Firms

Diversity Index - Combination of Multiple Sectors

The level of diversification of individual firms is measured by the diversity index. By expansion and contraction at the establishment level and market diversification at the firm level, individual firms may have different combinations of gross revenues in different number of sectors. The market diversification increases the number of sectors

in which a firm operates its business by running multiple establishments. Meanwhile, expansions and contractions change employment sizes at the establishment level.

Figure 7.6 shows different combinations of multiple sectors that determine various values of diversity index for the model firms. It shows, for firms classified by diversity index, in how many sectors firms have their establishments. Firms with low diversity index, in how many sectors firms have their establishments. Firms with low diversity indices operate their establishments in small numbers of sectors. In contrast, firms with high diversity indices have their business in large numbers of sectors.

For example, consider firms that have diversity index 0.6 in Figure 7.6 (represented by a dotted line with '×' in the figure), about 70% of these firms have their businesses in four sectors, about 30% of them have their businesses in five sectors, and the other remaining firms have their establishments in six or seven sectors. Note that the diversity index varies depending on different combinations of gross revenues in each sector as well as the number of sectors where a firm has its business as explained in Chapter IV.

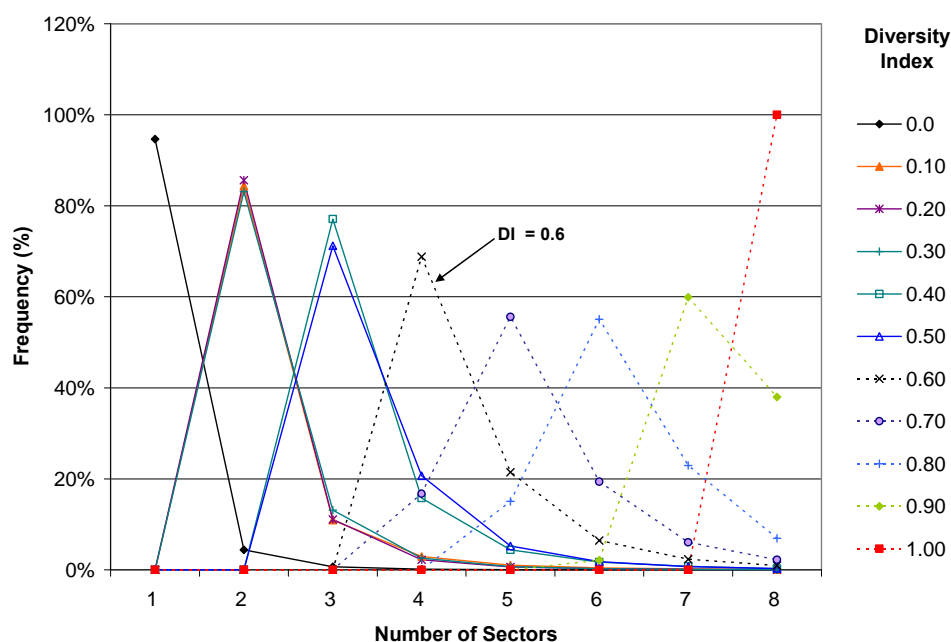


Figure 7.6 Distribution of Firms by the Number of Sectors, Classified by DI

Industry Ratio: Industry Revenues to Industry Capacity

A ratio of the industry total revenues to the industry total capacity (total employment) is measured in the model. The value of this industry ratio is about 0.235 from the simulation. It means that one employee in the large construction firms in the model corresponds to about \$235,000 in revenue. This measure of gross revenues per employee is very close to the actual revenue rates (0.241) measured using the real U.S. construction industry data in Table 6.4 in Chapter VI.

It should be noted that the value of the industry ratio is obtained without representing any specific variables for the firms' productivity in the model. The ratio is great at the initial condition since all firms are the same and relatively small compared to

the assumed total amount of jobs in the market (constant market demand). Over periods, individual firms grow, diversify, or contract and the total industry capacity finds equilibrium associated with the amount of jobs available in the market. A sensitivity analysis is performed on this industry ratio assuming different initial sizes of firms in Section 7.4.

7.2 Comparison of the Two Methods

In Chapter V, a new method was introduced to represent contractors' go/no-go decision depending on their risk attitudes. Since expected utility theory has developed its theoretical grounds in the literature over decades and it have been favored in decision science and management studies, the new method can be validated by comparing it to the conventional method using expected utility theory and utility functions.

7.2.1 Value at Risk vs. Utility Function

Range of Maximum Loss Allowances in the New Method

In the new method, contractors' MLA was assumed to be between 22% and 96% of the mean of the project cost, which is taken as \$10M in the evolutionary model. Thus, the upper limit of maximum loss allowance for any contractor is \$9.6M ($= \$10\text{M} \times 0.96$) and the lower limit of the maximum loss allowance is \$2.2M ($= \$10\text{M} \times 22\%$).

Therefore, the most risk-tolerant contractor in the model makes a go decision unless the expected value of loss (VaR) for a job is greater than \$9.6M. In contrast, the most risk-averse contractor in the model makes a go decision unless the expected value of loss (VaR) for a job is greater than \$2.2M.

From simulation of the model, it was found that contractors that have MLA smaller than 22% hardly ever make go decisions in bids. These contractors' participation in competition is meaningless: they hardly ever bid, obtain no jobs, and go out of business soon after their founding.

Parameter r in the Utility Function

The normalized exponential utility function in Equation 5.10 in Chapter V has three parameters: a , b , and r . Below is the reproduced equation of the normalized exponential utility function (same as Equation 5.10).

$$\begin{aligned} \text{if } r \neq 0, U(x) &= \frac{1 - \exp(-(x-a)r)}{1 - \exp(-(b-a)r)} \\ \text{if } r = 0, U(x) &= \frac{(x-a)}{(b-a)} \end{aligned} \quad [7.1]$$

Where, r is a risk-aversion coefficient to define risk attitude;

x is the wealth (contractor's bid) and $x > 0$;

a is the minimum value of wealth;

b is the maximum value of wealth; and $b > a$.

Values of the parameters can be any value. Note that the wealth is the value of the gain for a single job under consideration, not the total wealth of the contractor.

Values of the parameters were determined in order to have compatibility between the two methods: the same possible range of bids by the model firms and a compatible range of different risk attitudes. The values of the parameters were determined as given below:

- The risk-aversion coefficient r varies from -0.33 to 0.24 (positive being risk-averse, negative being risk-seeking, and zero being risk-neutral);
- The minimum value of wealth (the minimum price, a) = \$6.0M; and
- The maximum value of wealth (the maximum price, b) = \$14.0M;

Figure 7.7 shows the normalized utility functions with the determined parameter values and ranges.

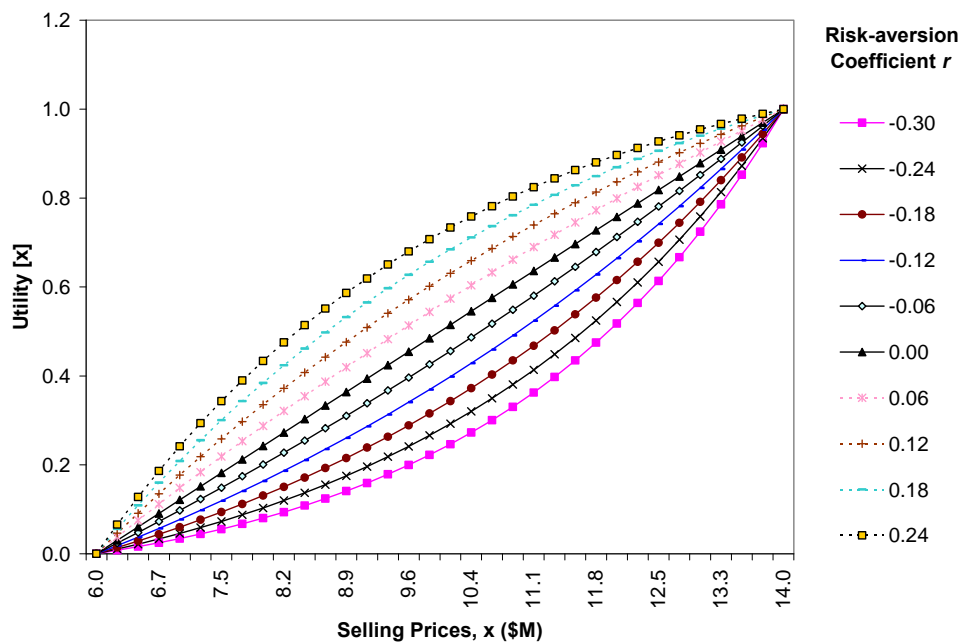


Figure 7.7 Normalized Utility Functions after the Parameter Adjustment

Comparison of Budget Thresholds in the Two Methods

The two methods are compared in their representation of contractors' go/no-go decisions. Using the two methods, Figures 7.8 and 7.9 show budget thresholds where individual contractors having different risk attitudes make go/no-go decisions depending on their perception of risk. The conventional method uses the above determined parameters.

In Figure 7.8, the maximum loss allowance varies from 22% to 99% of the mean of cost \$10M (i.e., from \$2.2M to \$9.6M) in the new method. Meanwhile, the parameter r in the normalized utility function varies from -0.33 to 0.24 in Figure 7.9.

Corresponding to values on the MLA axis in Figure 7.8, the budget threshold using the new method varies from \$7.7M to \$11.4M. Using the conventional method, the budget threshold varies from \$7.9M to \$11.7M in Figure 7.9. In the overall shape, there are minor differences in curvature. The line of budget thresholds using the conventional method is straighter than the line of budget thresholds using the new method.

The locations of risk-neutrality on the horizontal axis are different between the two methods. Risk-neutrality in the conventional method is found at $r = 0$ in Figure 7.9 that corresponds to budget threshold \$10M (equal to the expected cost). This value corresponds to $MLA = \$5.6M$ (56% of the expected cost) as shown in Figure 7.8. Hence, risk-neutrality using the new method corresponds to a threshold of \$5.6M.

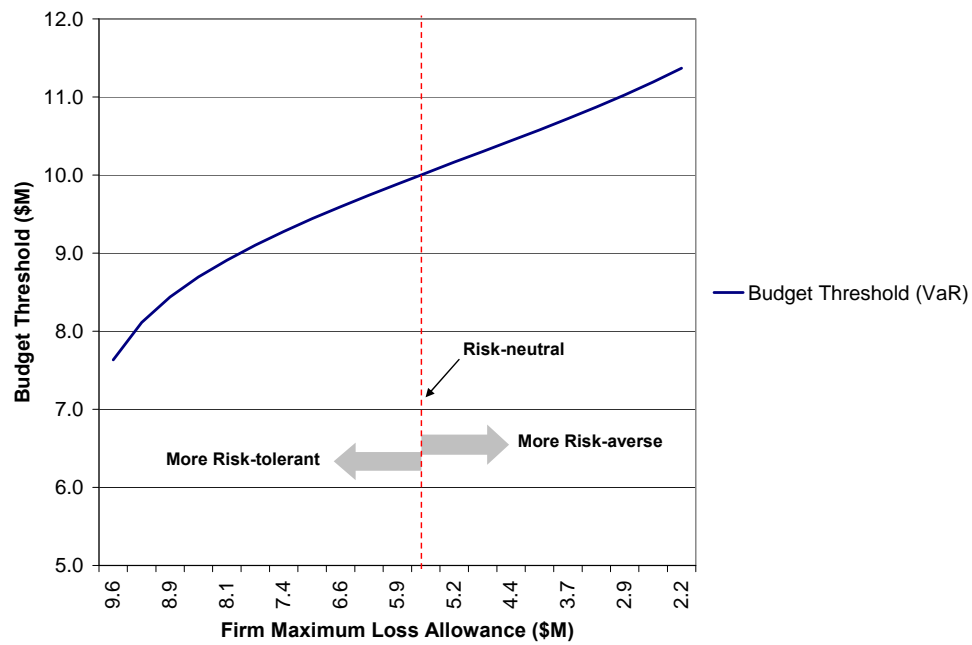


Figure 7.8 Budget Threshold Using Value at Risk

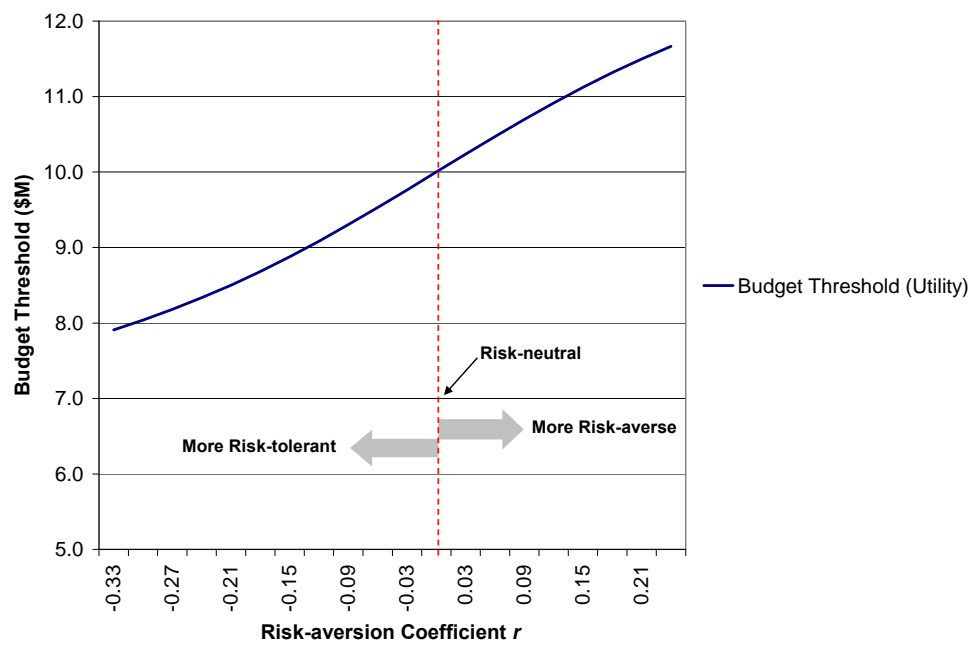


Figure 7.9 Budget Threshold Using the Assumed Utility Functions

The comparison of the two methods shows compatible ranges of possible bids and various risk attitudes. Even though there are minor differences in shape and curvature, there are no significant differences between the two methods in representing contractors' go/no-go decisions.

7.2.2 *Comparison of the Simulation Results*

In order to determine if there are any differences in simulation results using the two methods, the aggregate patterns are compared. Figure 7.10 shows the comparison of two distributions of firms by their risk attitudes. *Uniform prior* reflects the uniform distribution used for the random assignment of risk attitude at the beginning of each simulation. So, higher frequencies represent longer survival. The most favorable degree of risk attitude is found at the mode in each distribution. The optimum risk attitude is found at 0.035 for risk-aversion coefficient r using expected utility and at MLA \$4.9M using VaR. The overall patterns are similar and the locations of the most favorable degree of risk attitude are indistinguishable. As found earlier, risk-neutrality corresponds to a threshold of \$5.6M using VaR and a threshold of $r = 0$ using expected utility. However, note that the locations of risk-neutrality on the horizontal axis are different between the two methods as shown in Figures 7.8 and 7.9.

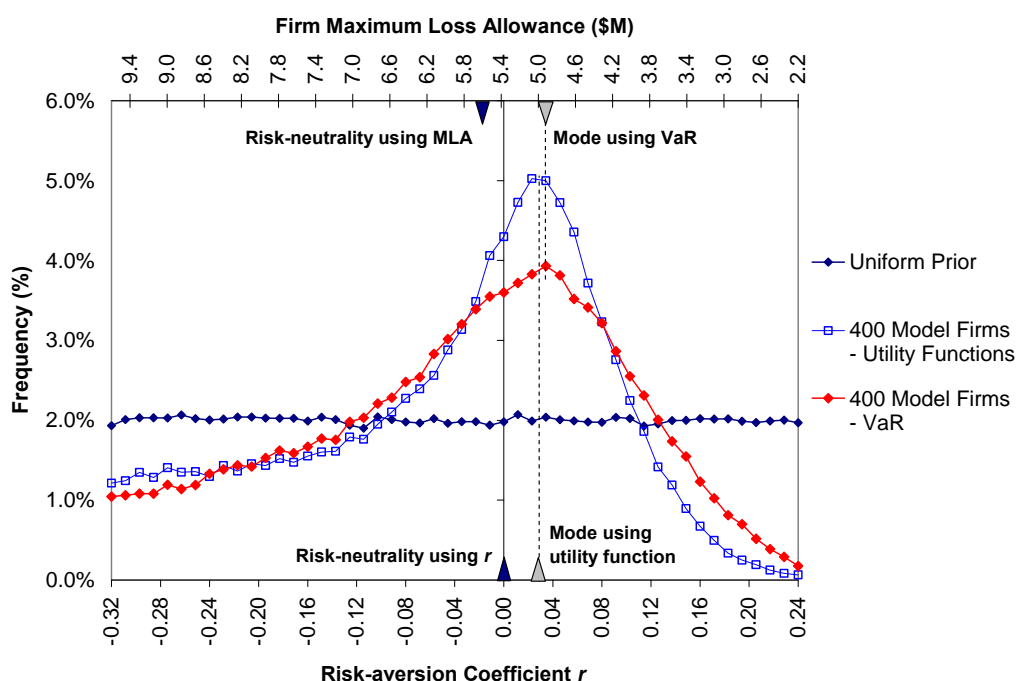


Figure 7.10 Comparison of Two Distributions of Firms, VaR vs. Expected Utility

In addition, the size distributions of firms derived by using the two methods are compared in Figure 7.11. The patterns are very similar to each other. Another similarity is also found in the diversification patterns of the model firms using the two methods, which are shown in Figures 7.12. and 7.13. Figure 7.12 shows the distribution of firms by diversity index and Figure 7.13 shows the number of sectors per firm. The two methods yield virtually identical diversification patterns compared to the actual ENR data.

Based on these comparisons, the two methods are similarly usable to represent the individual differences in contractors' risk attitude and their risk-taking behaviors. However, the proposed new method has an advantage over the conventional method due

to its simplicity and practicality: the risk measures used are dollars and it describes better how real managers perceive their business risks.

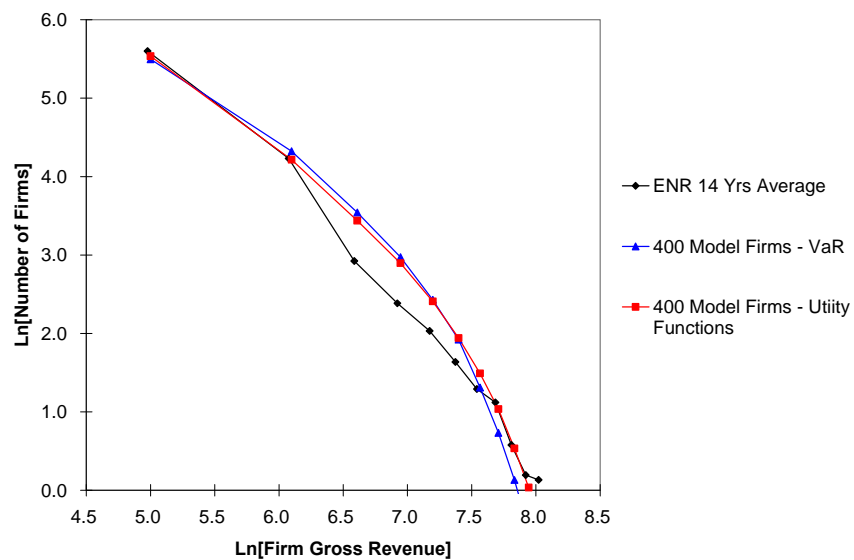


Figure 7.11 Distribution of Gross Revenue

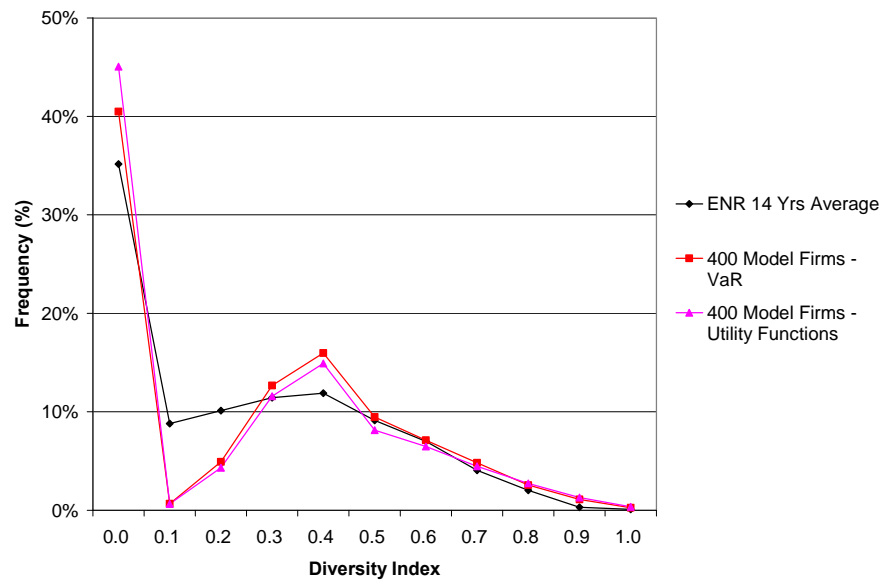


Figure 7.12 Distribution of Firm Diversity Index - VaR

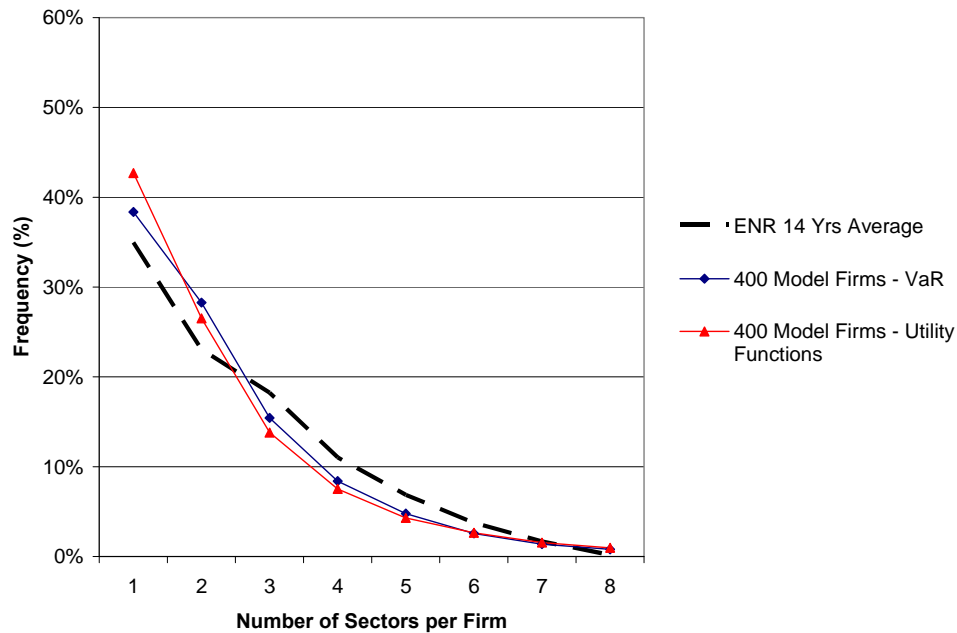


Figure 7.13 Number of Sectors per Firm – VaR vs. Utility Functions

7.3 Test of Hypotheses

The five hypotheses were developed in Chapter V to investigate latent but critical relationships between risk attitude and contractors' competitive success in the market. These hypotheses have been tested using the evolutionary simulation model. To analyze differences in risk-taking behaviors and resultant performance among the model firms that have different risk attitudes, the firms are classified by the amount of MLA as shown in Table 7.2. For the classified groups, the same relative classification of risk attitude used for the development of hypothesis in Chapter V is applied to describe their characteristics: most risk-tolerant; moderately risk-tolerant; moderately risk-averse; and

most risk-averse. Note that, in this simplified classification, group 3 that represents moderately risk-averse firms also includes risk-neutral firms with $MLA = \$5.6M$. The simulation results, however, identify difference between risk-neutrality and moderate risk-aversion, which is discussed through the hypothesis tests and sensitivity analyses.

Table 7.2 Classification of Model Firms by MLA

Groups	Range of MLAs	% of the Mean of Cost	Level of Risk Attitude
Group 1	\$7.75M ~ \$9.6M	77.5% ~ 96.0%	Most risk-tolerant
Group 2	\$5.90M ~ \$7.75M	59.0% ~ 77.5%	Moderately risk-tolerant
Group 3	\$4.05M ~ \$5.9M	40.5% ~ 59.0%	Moderately risk-averse
Group 4	\$2.20M ~ \$4.05M	22.0% ~ 40.5%	Most risk-averse

7.3.1 Distributions of Winning Bids and Success Rates

Before the hypothesis tests, the study analyzes risk-taking behaviors of different firms, which were the basic reasoning of the proposed hypotheses. Contractors' different risk-taking behaviors can be found in their winning bids. Figure 7.14 shows the distribution of winning bids for different groups of model firms classified by the amount of MLA. Most risk-tolerant contractors (group 1) win jobs with low bid amounts and their distribution has the greatest variance compared to the other groups' distributions. Most risk-averse contractors (group 4) have the narrowest distribution and the distribution is skewed to the right.

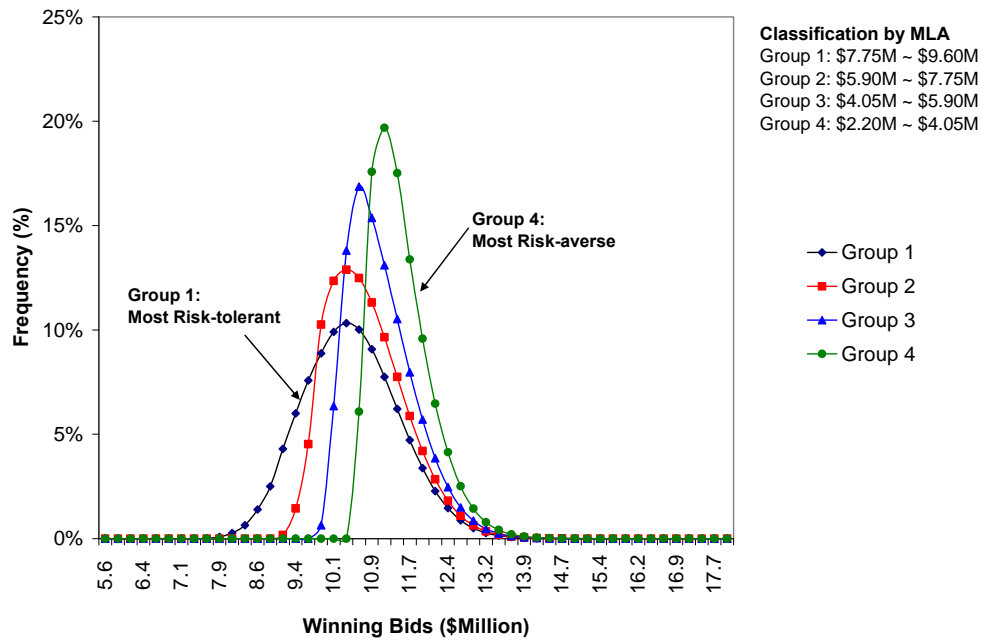


Figure 7.14 Distribution of Winning Bids

The firms classified into four groups in Figure 7.14 have the opposite order in their success rates which is defined in Equation 7.2. Figure 7.15 shows the distribution of different risk attitude groups by their success rates. Most risk-tolerant contractors (group 1) have the highest success rate, but with the greatest variance. In contrast, most risk-averse contractors (group 4) have the lowest success rate with the smallest variance. The moderate risk-averse contractors (group 3) have some moderate level of success rate, which is lower than that of moderate risk-tolerant contractors (group 2).

$$Success\ Rate(\%) = \frac{Number\ of\ Wins}{Number\ of\ Bids} \times 100 \quad [7.2]$$

These distributions of winning bids and success rates in Figures 7.14 and 7.15 show the advantages and disadvantages that were expected in the development of hypotheses in Chapter V. Moderately risk-averse and moderately risk-tolerant contractors locate in the middle of the two extreme risk attitude groups (most risk-tolerant and most risk-averse) in these measures.

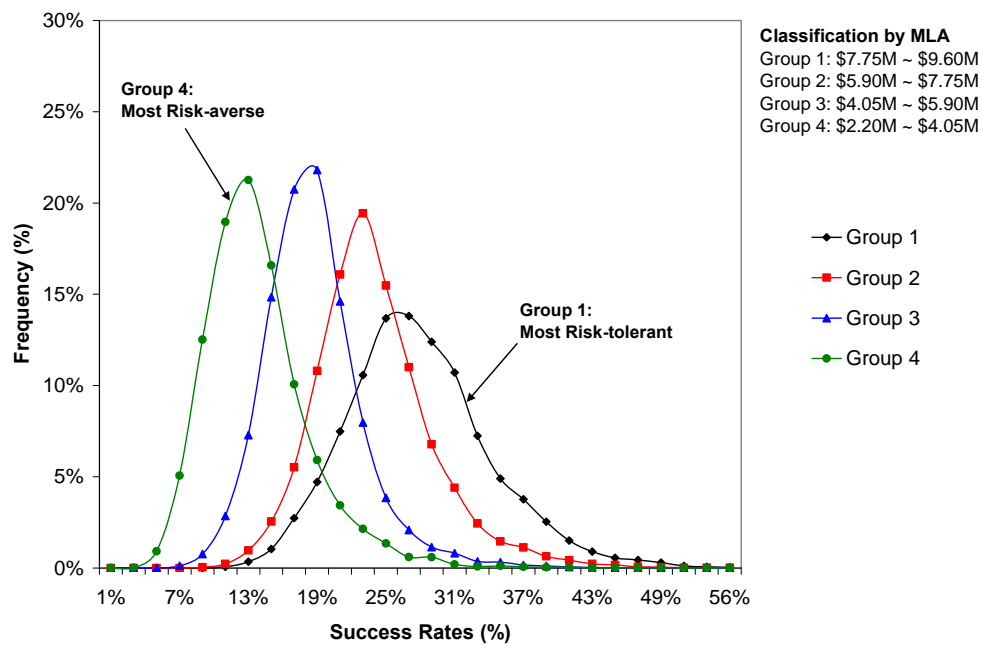


Figure 7.15 Distribution of Firms by Success Rate, Classified by MLA

7.3.2 Hypothesis 1: Profitability vs. Risk Attitude

H1. Moderately risk-averse contractors would have more firm profits than other contractors.

Hypothesis 1 expects that moderately risk-averse contractors would make a trade-off between the extremes of advantages (more jobs by being most risk-tolerant and

more profit per job by being most risk-averse) and disadvantages (possible large loss by most risk-tolerant and fewer jobs by being most risk-averse) by taking their business risks in a moderate way. Figure 7.16 shows the distribution of firms' annual profits when the firms are classified by MLA. Moderately risk-averse firms (group 3) show better performance (the longest tail to the right) than other firms. That is, there is an optimum value for risk-aversion such that firms using this strategy are more successful than others.

However, as shown in the figure, group 3 also has longer tails to the left. It is because the moderately risk-averse firms grow based on the better performance and perform more jobs in the market. The longer tails represent that there are always uncertainties inherent in construction jobs, and performing more jobs means taking more downsides as well as more upsides of risk.

In addition, Figure 7.17 shows the distributions of firms' cash reserves when the firms are classified by MLA. The moderately risk-averse contractors (group 3) have the most right skewed distribution, indicating their outperformance over other contractors. The moderately risk-averse contractors build a better financial strength based on more annual profits and reduced risk of loss. Most risk-tolerant contractors (group 1) show the worst financial condition. Most risk-averse contractors (group 4) show a better financial condition than group 1, but worse than groups 2 and 3.

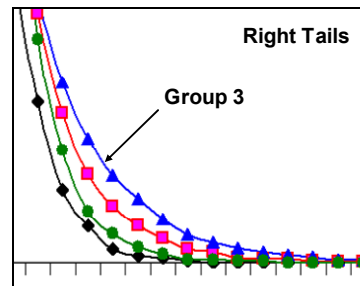
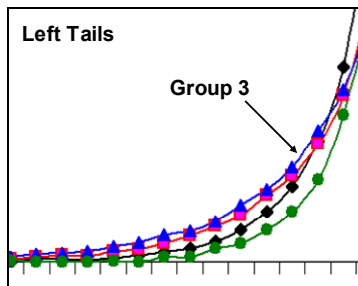
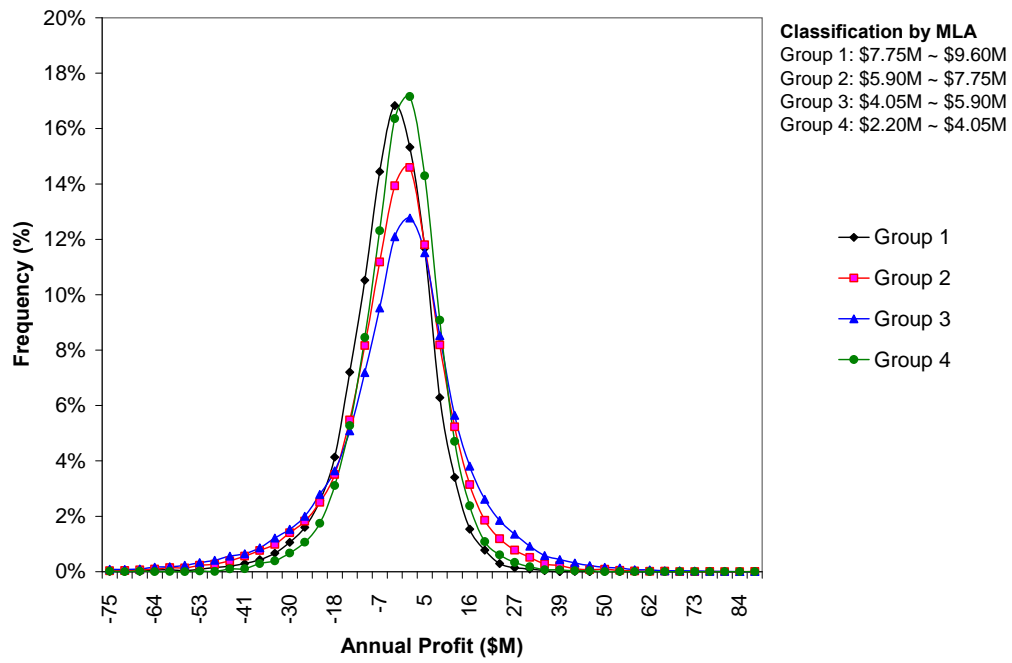


Figure 7.16 Distribution of Firm Annual Profits

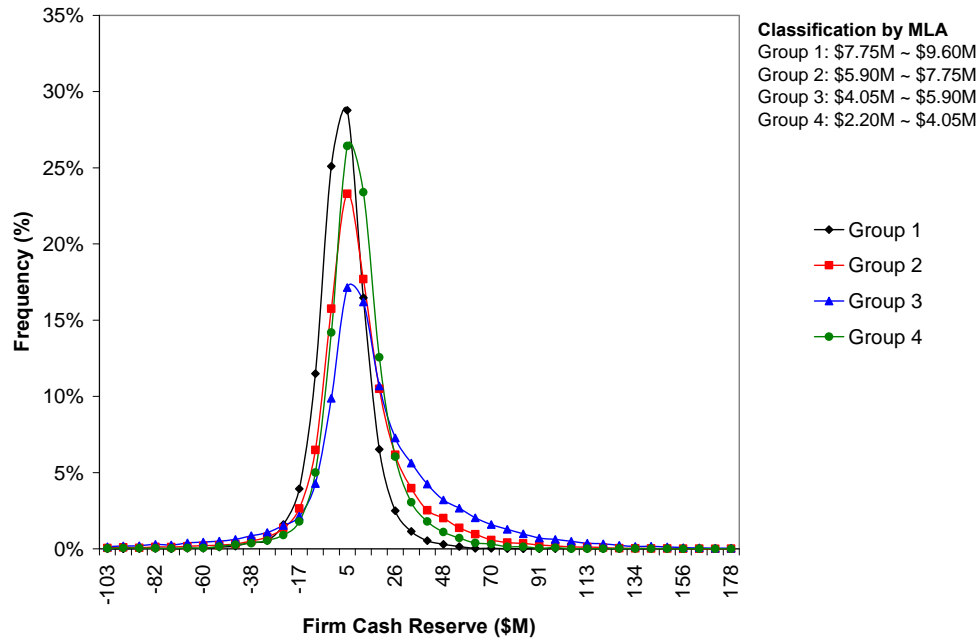


Figure 7.17 Distribution of Firm Cash Reserves by the Degree of Risk-aversion

7.3.3 Hypothesis 2: Survival vs. Risk Attitude

H2. Moderate risk-aversion is advantageous for survival in the construction market.

Hypothesis 2 expects that moderately risk-averse contractors would survive better than other types of contractors. The moderately risk-averse contractors would have stable business operations since they do not take too large risks, which could result in large losses. Also, they take moderate risks to avoid risks of overhead burden due to fewer jobs. Moderately risk-tolerant contractors make a trade-off between the amount of jobs and the profitability of job won. However, they are exposed to risk of large losses, which is more critical than risk of overhead burden.

Figure 7.18 shows the distribution of the 400 model firms by their risk attitude (represented by MLA). The figure shows historical changes in the distribution over periods. The shape of the distribution becomes stable after about iteration 40, indicating that the steady state has been reached. The changes are the result of competition. Some contractors survive while others disappear. It is a graphical representation of the evolutionary process within the model. Moderately risk-averse contractors (group 3) become dominant in the population indicating their longer survival while frequencies of most risk-tolerant contractors (group 1) and most risk-averse contractors (group 4) become low. The most risk-tolerant contractors and the most risk-averse contractors lose their population quickly. Contractors that are moderately risk-tolerant (group 2) increase in population, but not as much as moderately risk-averse contractors.

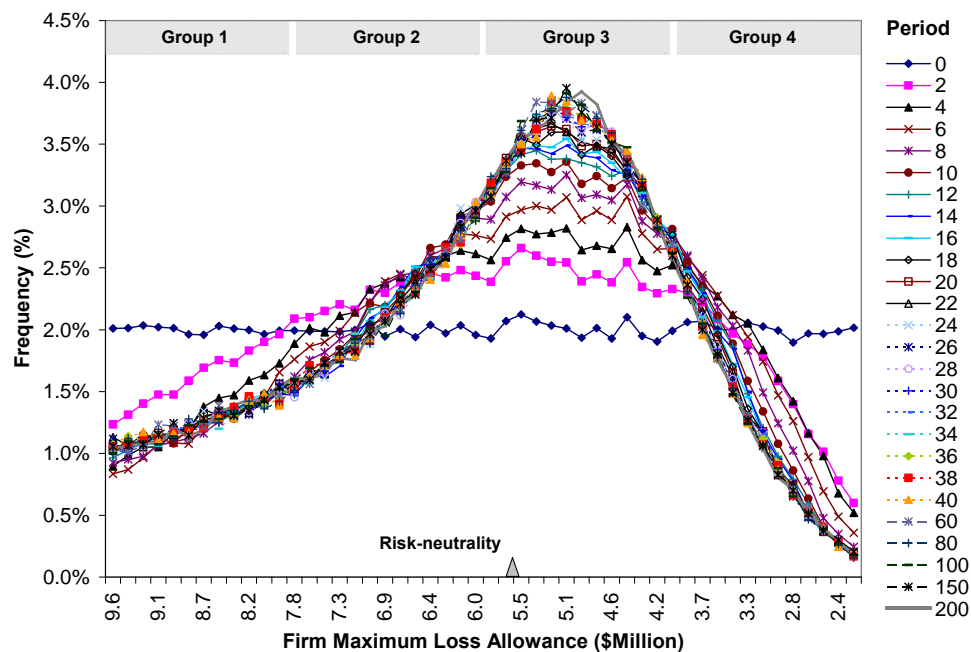


Figure 7.18 Distribution of the 400 Model Firms' MLA

In Figure 7.18, the most favorable level of risk attitude is found to the right of risk neutrality (MLA = \$5.6M). The surviving contractors are more risk-averse from the risk neutrality. Among the 400 firms, each group, from groups 1 to 4, has 63 firms (15.7%), 108 firms (27.0%), 172 firms (43.0%), and 57 firms (14.2%) at the steady state, respectively. The moderately risk-averse contractors are dominant in the population. Based on the analysis, moderate risk-aversion is in favor of survival in the construction market.

7.3.4 Hypothesis 3: Growth vs. Risk Attitude

H3. Moderate risk-aversion is in favor of growth of contractors in the construction market.

Hypothesis 3 expects moderately risk-averse contractors' growth based on their better economic performance (as proposed in H1) and longer survival (as proposed in H2). Figure 7.19 shows the distribution of firm gross revenues by the degree of risk attitude. Moderately risk-averse contractors (group 3) have the most right skewed distribution, which indicates their growth at the expense of other groups. Most risk-averse contractors (group 4) show the worst performance in growth. They are selective in their bid decisions and cannot obtain enough jobs to grow. Most risk-tolerant and moderately risk-tolerant contractors (groups 1 or 2) also show an unfavorable performance in their growth. They can obtain more jobs by taking risks in their bid decisions. However, they cannot grow as much as the moderately risk-averse contractors since they cannot survive longer because they run higher risk of losses as

found in hypothesis 2. Based on this analysis, moderate risk-aversion is in favor of growth in the competitive construction market.

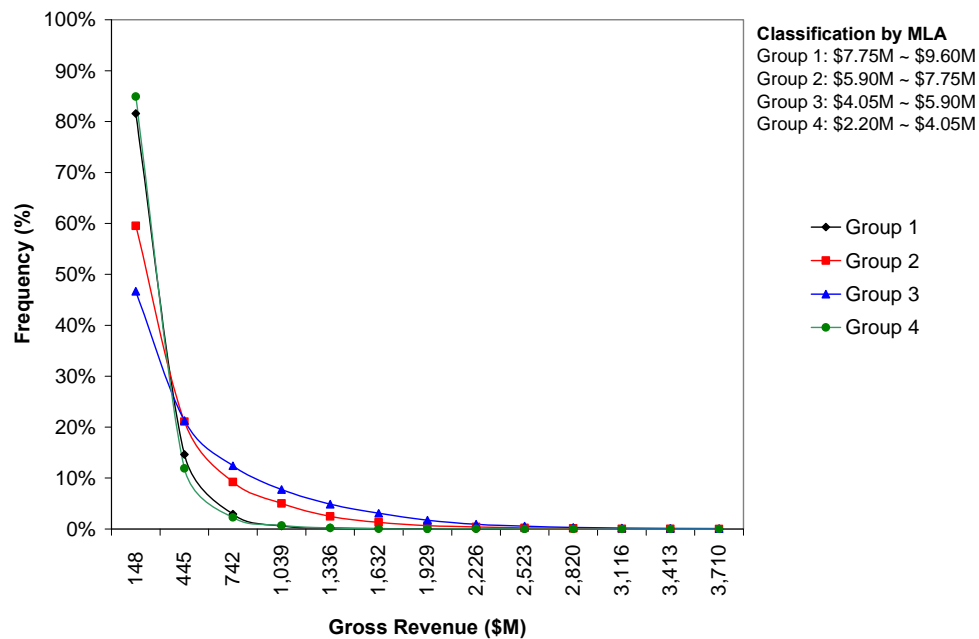


Figure 7.19 Distribution of the 400 Model Firms' Gross Revenues

7.3.5 Hypothesis 4: Diversification vs. Risk Attitude

H4. Moderate risk-aversion is in favor of diversification.

In Hypothesis 4, moderately risk-averse contractors are expected to be more successful in diversification than other contractors. The success of diversification depends on how a new establishment competes in a new sector. Establishments inherit their parent firm's risk attitude. Based on the reasoning in Hypotheses 1 and 2 about profitability and survival, moderate risk-aversion is expected to outperform at the

establishment level. Therefore, moderately risk-averse contractors have higher probability of success in their diversification.

Figure 7.20 shows the distributions of firms by their risk attitude while the firms are classified by their diversification levels. The classified firms show distinct distributions. Moderately risk-averse contractors (group 3) are diversified more than other contractors. Most of other contractors are less diversified or specialized. Note that the most favorable risk-aversion level is found to the right of risk neutrality. As a result, contractors that are most highly diversified tend to be moderately risk-averse.

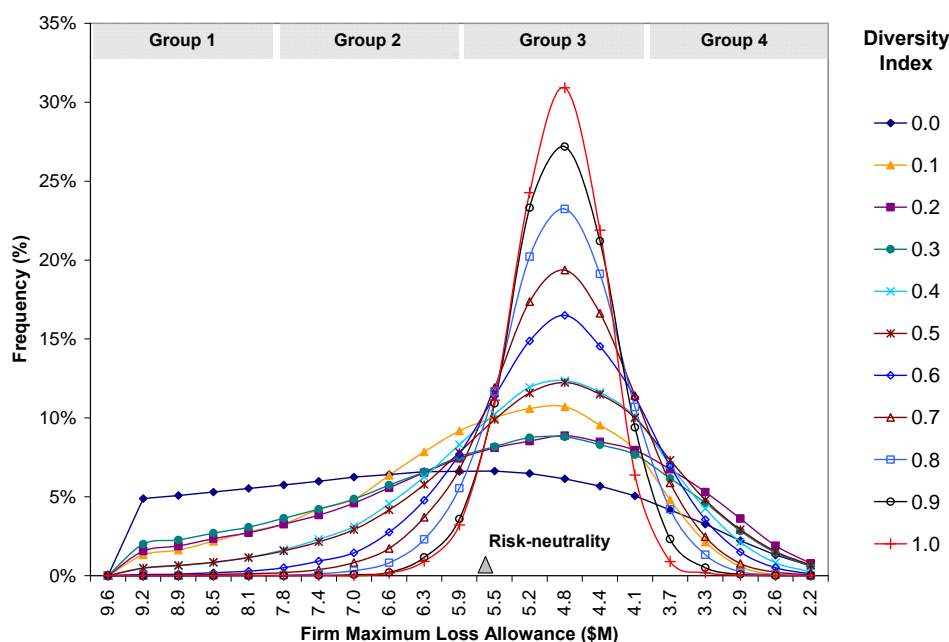


Figure 7.20 Distribution of Firm Maximum Loss Allowance for Various DIs

Figure 7.21 provides the number of sectors per firm by risk attitude group.

Moderately risk-averse contractors (group 3) have the highest frequencies with greater

number of sectors (5 to 8 sectors per firm) than other groups. On the contrary, more than 60% of most risk-tolerant contractors (group 1) operate in only one sector. Most risk-averse contractors (group 4) are more diversified than contractors in groups 1 and 2, but less diversified than moderately risk-averse contractors. Therefore, moderately risk-averse contractors are more successful in diversification than all other contractors.

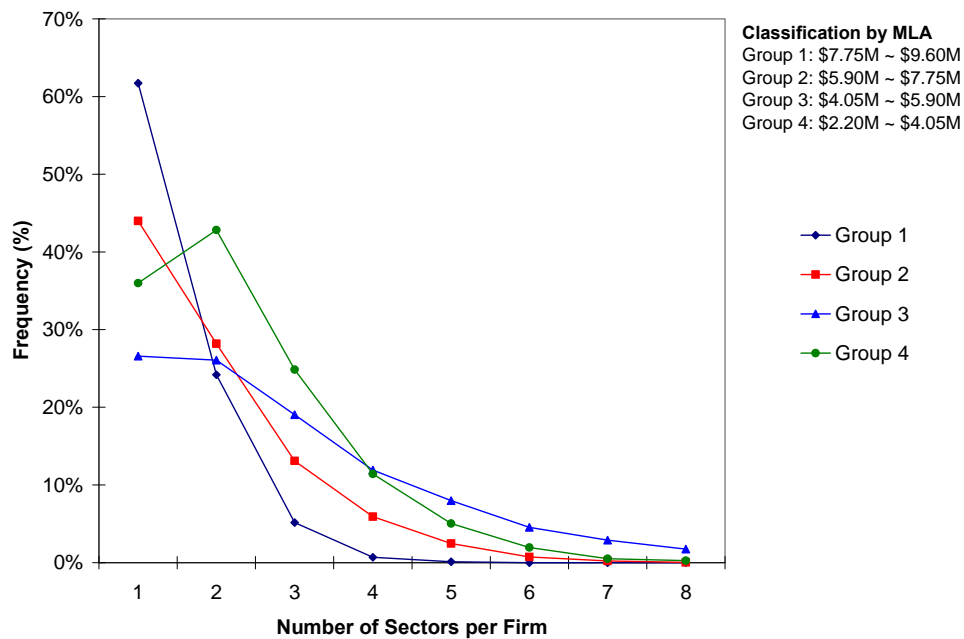


Figure 7.21 Number of Sectors per Firm by Aversion Group

In the real business world, diversified contractors perform different jobs in different market sectors, such as residential, non-residential, commercial, power system, petroleum, highway, other civil, etc. The different businesses would have different characteristics with respect to business risks and competition. Note that the multiple market sectors in the current model are not differentiated. Even in the absence of other

factors inherent in different types of jobs, the model produces the aggregate patterns similar to the actual industry patterns in the size distribution of contractors and the pattern of their market diversification at the same time. It indicates that the effects of contractors' organizational risk attitudes are so critical that the strengths of moderate risk-aversion are effective in different market sectors.

7.3.6 *Hypothesis 5: Diversification vs. Survival*

H5. More diversified contractors have longer longevity.

Based on the previous hypotheses, especially Hypotheses 2 and 4 which are about the relationships of risk attitude with survival and diversification, moderately risk-averse contractors are expected to be more diversified and to live longer because a diversified firm would have multiple establishments as multiple buffers against market risk and subsequent firm failure.

Figure 7.22 shows the age distributions of firms classified by their diversification level. Note that the ages shown are periods, not years. The figure shows that more diversified firms live longer and less diversified firms fail sooner. From Hypothesis 4, it was found that moderately risk-averse contractors are more diversified. Therefore, the current test extends its result to maintain that moderately risk-averse contractors are more diversified and they live longer in the construction market.

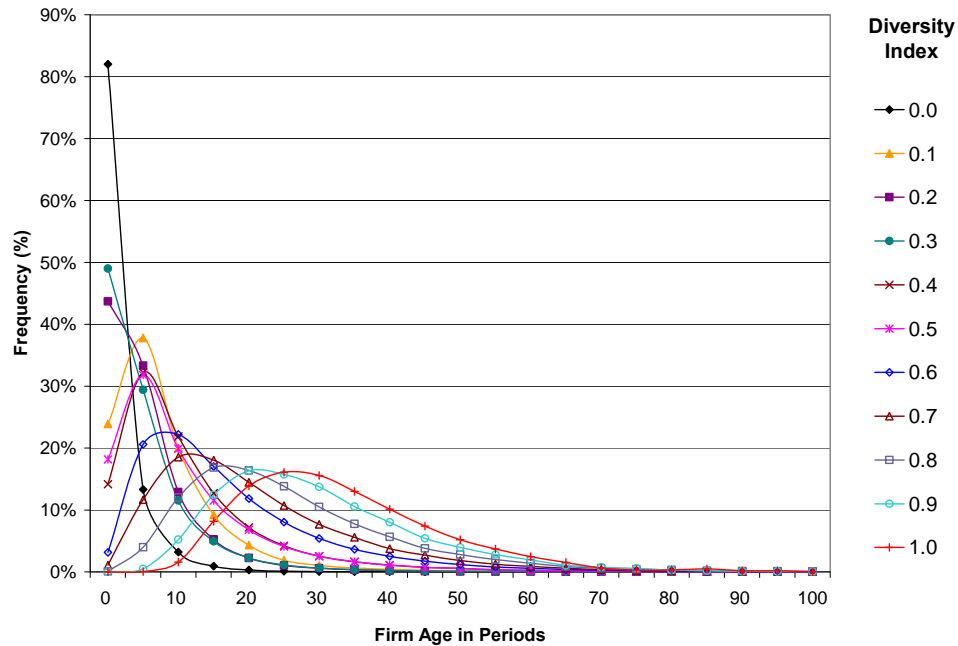


Figure 7.22 Age Distribution of Firms by Diversity Index

In the real business world, it is found that large firms have been performing their business over decades. They have been successful in their businesses over time periods and they have grown. So, an additional hypothesis can be developed by expecting that larger contractors would live longer than smaller contractors. Figure 7.23 shows the age distributions of firms classified by their capacity (employment size). The figure indicates that large contractors live longer: size and age are positively correlated, or that contractors that survive longer have the opportunity to grow.

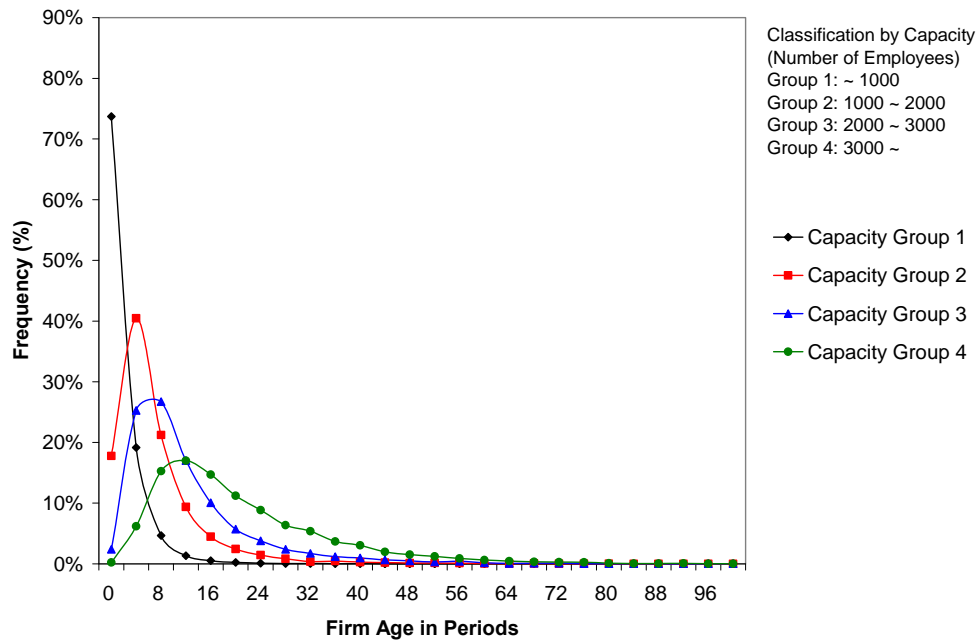


Figure 7.23 Age Distributions of Firms by Capacity

7.4 Sensitivity Analyses

Three sensitivity analyses are performed. The first analysis is performed to test different assumptions on contractors' risk attitude. The model considers heterogeneity in risk attitude among contractors. Against this, two different assumptions are tested: *no risk-aversion* and *all risk-neutral* for contractors. The second analysis is conducted to test different prior distributions used for random assignment of risk attitude to individual firms. The last test is about the initial conditions for the firms, especially the initial size of firms.

7.4.1 *Different Assumptions on Risk Attitude*

The current model allows variable risk attitudes for contractors. What if contractors have identical risk attitudes? By testing different assumptions on contractors' risk attitude, the critical effects of risk aversion are highlighted as below.

Assumption of No Risk-aversion

No Risk-aversion in Figure 7.24 is the size distribution of the model firms under the assumption of no risk-aversion for all firms: the firms always make go decisions regardless of risk. The assumption results in no large firms (luck does not last long enough for the firms to grow) and more middle size firms. The simulation results do not match the ENR data, indicating that the assumption of no risk-aversion by contractors must be rejected; risk-aversion does matter.

The no risk-aversion assumption also results in a different diversification pattern of the model firms as shown in Figure 7.25. It shows a comparison between the actual industry pattern, the original simulation result, and the simulation result with the no risk-aversion assumption. Contractors' diversification is greatly reduced without risk-aversion. No risk-aversion is equivalent to extremely high risk-tolerance. As a result, contractors' risk attitude matters: without risk-aversion, contractors do not diversify and they cannot survive and grow in the long-run in the construction market and moderate risk-aversion is critical to firms' survival and growth.

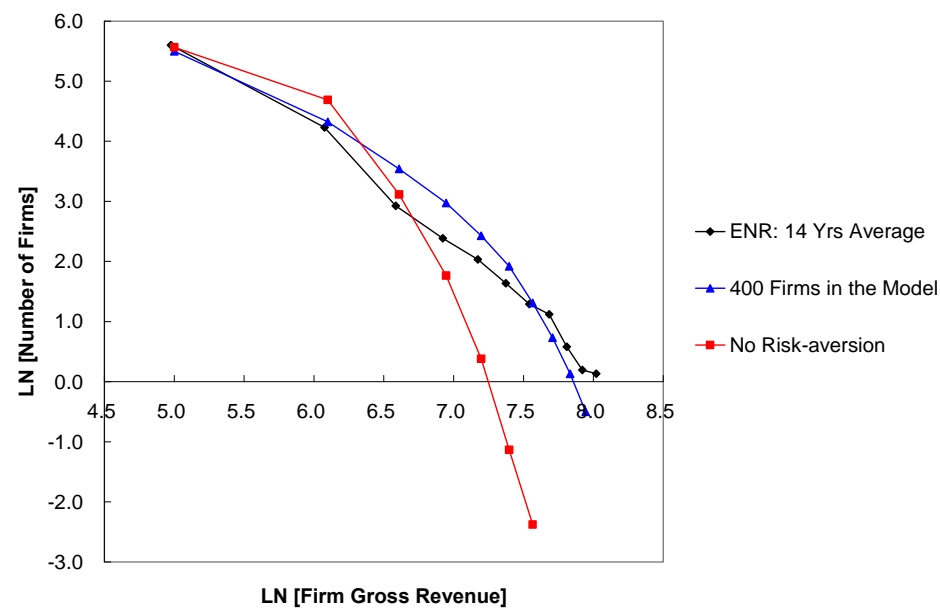


Figure 7.24 Size Distributions – No Risk-aversion

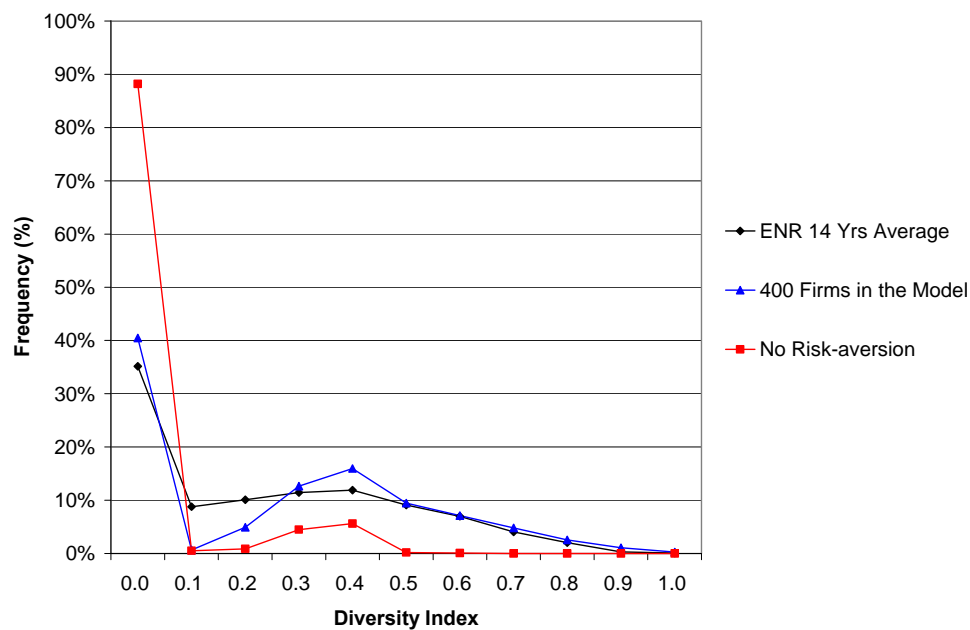


Figure 7.25 Diversification Pattern – No Risk-aversion

Assumption of All Risk-neutral

Another assumption is tested: what if all contractors are risk-neutral. A risk-neutral contractor is supposed to behave based on expected value theory: a decision maker makes a go decision if expected profit of a choice is greater than zero, and *vice versa*. It is different from the assumption of *No Risk-aversion* that does not allow no-go decisions.

The assumption of *All Risk-neutral* is implemented in the model by setting all firms' risk-aversion coefficient r at zero in their utility functions or by setting their MLA at \$5.6M. It was found in Figure 7.8 that the value of MLA equivalent to risk-neutrality is about 56% of the mean of the expected cost (therefore, \$5.6M), whereas the optimum risk-aversion corresponds to $MLA = \$4.9M$, found from the hypothesis tests.

Figure 7.26 shows the simulation result with the assumption of *All Risk-neutral*. This size distribution of all risk-neutral firms shows a better performance of the model firms compared to the simulation result with the assumption of no risk-aversion in Figure 7.24. However, compared to the actual size distribution and the original simulation result with various risk attitudes, there are still a smaller number of large firms than in the real data set. Therefore, the size distribution of firms under the all risk-neutral assumption does not match the industry data, which indicates that this assumption must be rejected. Again, the test confirms that risk-aversion does matter.

In addition, Figure 7.27 shows the diversification pattern of the all risk-neutral contractors. More firms are diversified than the results with the assumption of no risk-

aversion. However, there are fewer firms with high diversity indices compared to the actual diversification pattern and the original simulation result.

Therefore, the assumption of *All Risk-neutral* that all contractors are risk-neutral and contractors behave based on expected monetary value should be rejected. It is clear from Figure 7.26 that construction firms must be more risk-averse than risk-neutrality, which leads to moderate risk-aversion, to match the actual size distribution. The test also confirms that moderate risk-aversion is favored more than risk-neutrality in firm growth and market diversification.

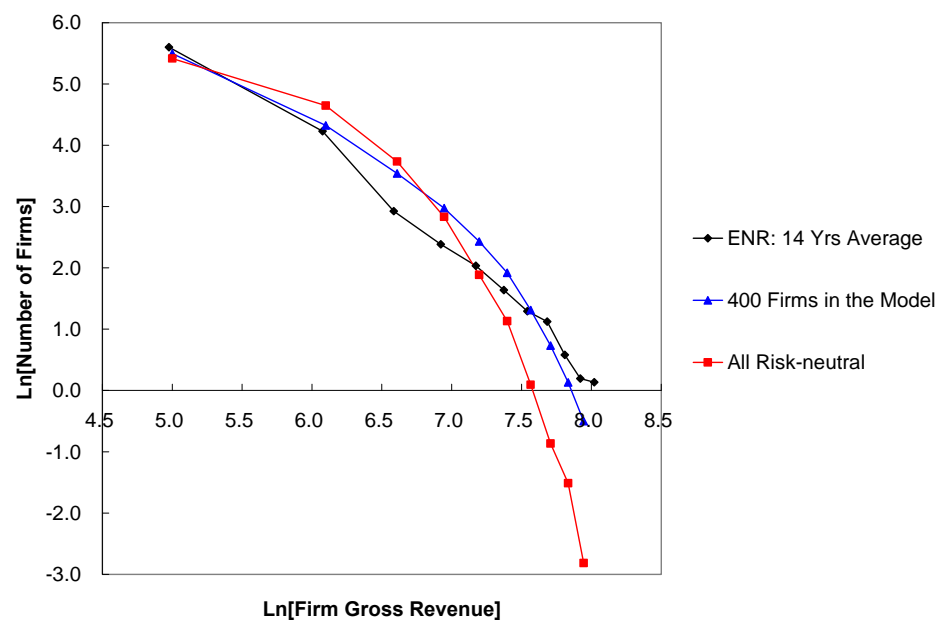


Figure 7.26 Size Distributions – All Risk-neutral

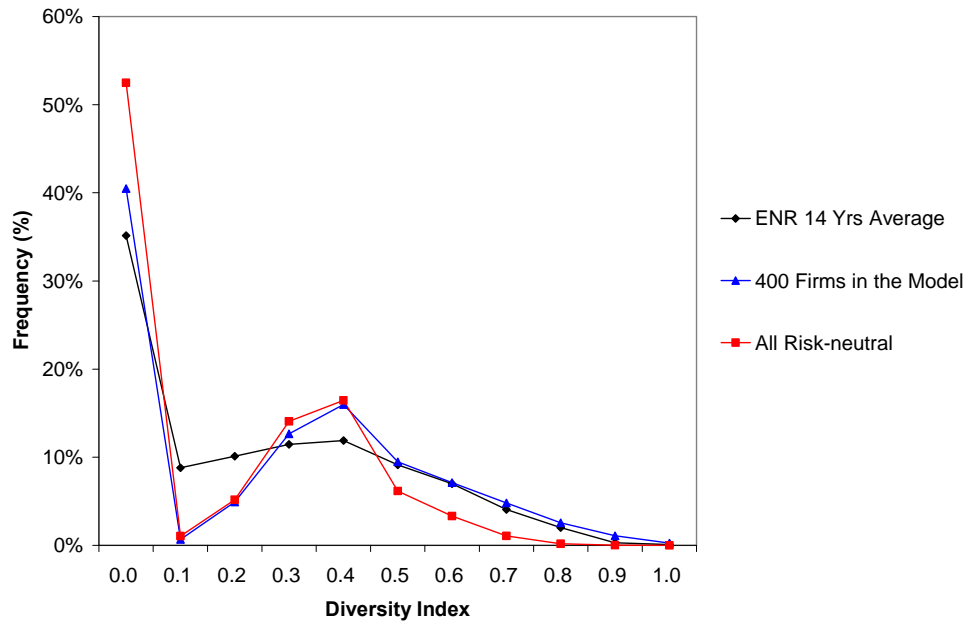


Figure 7.27 Diversification Pattern – All Risk-neutral

7.4.2 Different Assumption on Market Diversification

What if contractors do not diversify? *No Market Diversification* in Figure 7.28 shows the size distribution of 400 model firms assuming that the model firms are not diversified over different market sectors. So, all firms compete with their competitors within one market sector (their original sectors). As shown in the figure, without diversification, there would be no large firms.

In Figure 7.28, the curvature in the distribution is greater than those in the size distributions in Figures 7.24 and 7.25 that are based on the two earlier assumptions: *No Risk-aversion* and *All Risk-neutral*. The population has more middle size firms without the largest firms. Therefore, based on the simulation result, it is concluded that

diversification plays a critical role in growth of construction firms in the construction market.

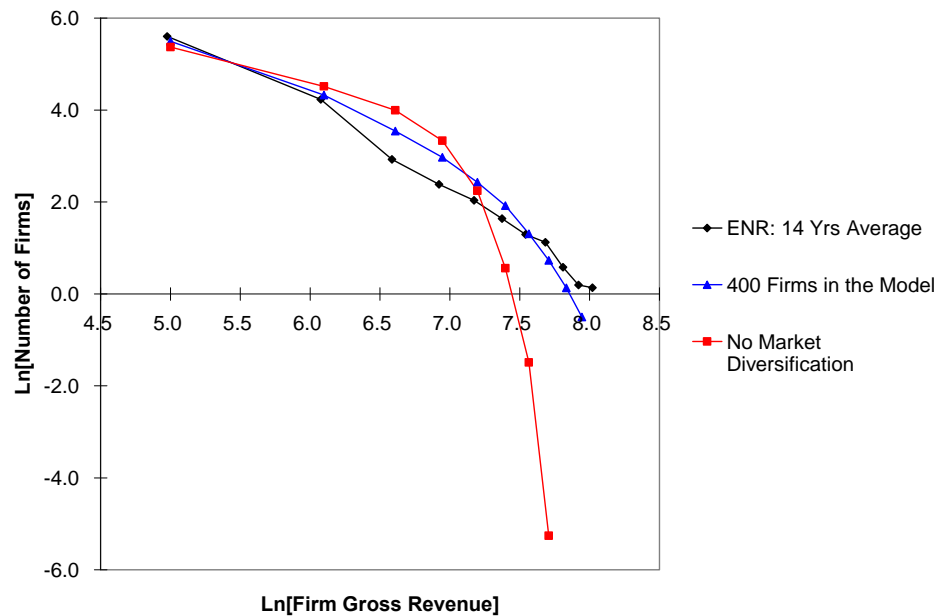


Figure 7.28 Size Distributions – No Market Diversification

7.4.3 Different Prior Distributions for Risk Attitude Assignment

One of the most meaningful results in the current study is the survival of moderately risk-averse contractors. Figure 7.18 showed changes in the distribution of the firm MLAs over periods starting from the uniform distribution. In the figure, the most appropriate level of risk-aversion in favor of survival is found. The assumption using the uniform distribution was intended to avoid generation of bias about the actual distribution. The uniform distribution is known as non-informative prior distribution because it conveys the least information (bias) of all possible distributions.

A sensitivity analysis was performed to investigate the effects of using different prior distributions. Figures 7.29 and 7.30 show the distributions of firm MLAs over periods using two different triangular distributions. As shown, the distributions are stabilized over the long-term and the ultimate distributions are identical to the size distribution using the uniform distribution. Refer to Figure 7.18 to see the distribution with the uniform distribution assumption. The three initial distributions lead to results that are indistinguishable after around period 30.

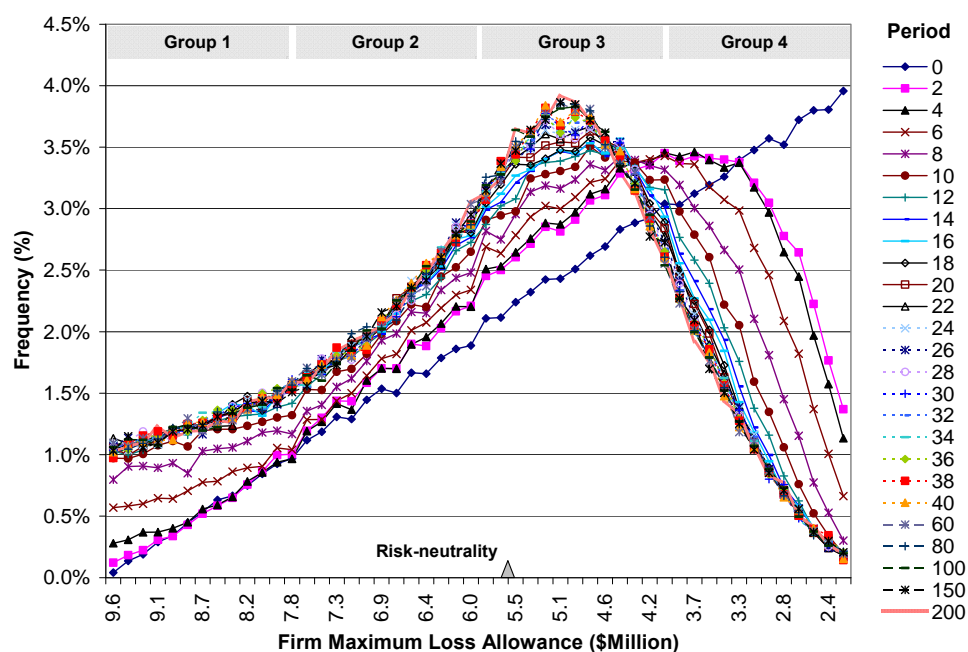


Figure 7.29 Distribution of Firms' MLA – Triangular Prior I

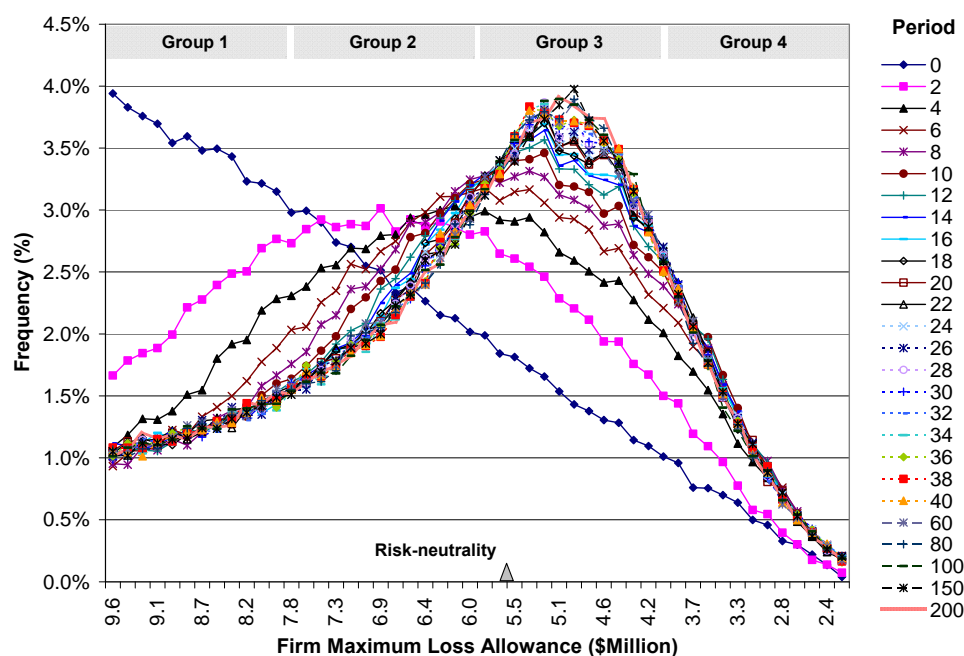


Figure 7.30 Distribution of Firms' MLA – Triangular Prior II

The identity among the three distributions indicates that the simulation results are not sensitive to the initial conditions, in particular prior distributions used for the random assignment of risk attitude. The system in the model quickly reaches the same steady state regardless of the initial distribution of the individual firms. Also, no significant differences are found in all other model behaviors with the different prior distributions.

7.4.4 Different Initial Sizes of Contractors

In the simulation model, initially, all firms are the same size. The assumed identical size for the initial population of firms is 250 employees. These identical firms become heterogeneous in size through competition over periods. Individual firms make employment changes by expansion, contractions, deaths, and market diversification

depending on their own performance. The assumed initial firm size is arbitrary. What if different initial sizes are assumed for the contractors in the model?

Effects by different initial sizes of firms are tested by monitoring the changes in the industry ratio, which was previously discussed using Figure 7.9. It is the ratio of the total industry revenues to the total industry capacity (employment size). The ratio becomes stable over periods and it represents a balance between industry capacity and demand in the market. It was found that the ratio is very close to the actual industry data. The equilibrium is attained in the model without any variables or specific rules for firms' productive performance on jobs. The equilibrium between the industry capacity and the market demand is also the result of competition.

Figure 7.31 shows the simulation results assuming different initial sizes: 500, 1000, and 2000 employees, compared to the original simulation result with 250 employees. For a better view, the figure shows only the changes in the industry ratio over the first 20 periods. Whatever initial sizes of the firms are assumed, the industry ratio reaches an identical steady state. The contractors' total capacity is balanced with the market demand given. The test confirms that the simulation results are insensitive to the assumptions of the initial sizes of the firms in the model.

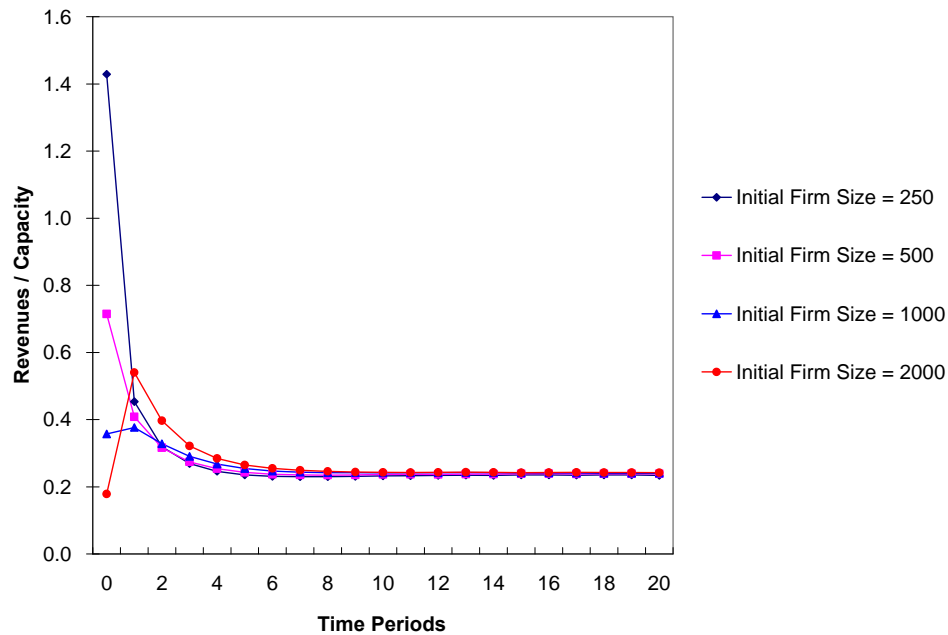


Figure 7.31 Industry Ratio: Total Revenues / Total Capacity

7.5 Summary

Three aggregate patterns were fitted to the actual industry patterns: size distribution of contractors, industry capacity changes, and diversification pattern. The model behaviors indicate the high explanatory power of the simple algorithm used in the model to represent contractors' competition in the market.

The current study proposes a new method for representation of construction contractors' risk attitude. The new method was validated through the comparison with the conventional method. While the two methods have no significant differences in the results, the proposed new method has its advantages over the conventional method. The

new method should be easy to understand and simple since the measures in the method are quantitative, i.e., amount of dollars. The conventional method using utility functions uses different degrees of curvature to describe the differences in risk attitude, which is not clear as much as the quantitative measure used in the new method.

The effects of risk attitude on contractors' competitive success were identified through the hypothesis tests. Moderate risk-aversion is favored in profitability, survival, growth, and diversification. Also, it was found that more diversified firms usually survive longer than less diversified firms.

In addition, sensitivity analyses were performed to figure out impacts by different assumptions and model parameters: *No Risk-aversion*, *All Risk-neutral*, different prior distributions for contractors' risk attitudes, and different initial sizes of firms. The tests using different risk attitude assumptions confirm that risk-aversion matters in the construction business. And, the tests using different individual conditions confirm that the simulation results are not sensitive to the initial conditions assumed for firms in the model.

As a result, the current study clarifies the latent but critical effects of risk attitude on competition and on individual contractors' competitive success, which are not available from the previous competition studies. The most appropriate level of risk-aversion outperforms risk-neutrality as well as all others: high risk-tolerance, moderate risk-tolerance, and high risk-aversion.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This study identifies how individual contractors' risk attitudes affect competition and the individuals' competitive success in the construction market. An evolutionary model has been developed, in which competitive bidding is represented as the major competition mechanism for contractors in the market. The model simulates and analyzes competition among multiple contractors that have their own risk attitudes. The study takes comprehensive and multiple perspectives considering effects of risk attitude at the individual level as well as the aggregate industry level. It also takes a long-term perspective by analyzing the success of firms within the domain of competition for the long-term.

As identified in this study, risk attitude is one of the most influential elements in competition. The study results confirm that risk attitude is critical to contractors' survival and growth. Introducing organizational risk attitudes to competition among individual contractors develops the unique pattern (power law) in the size distribution of contractors that is observed in the actual industry data. Also, aggregate effects as results of competition are identified in industry capacity changes and firms' diversification patterns. Following are the summarized conclusions.

The current study uses relative classification of contractors by the level of risk attitude: most risk-tolerant, moderately risk-tolerant, moderately risk-averse, and most risk-averse. Most risk-tolerant contractors are willing to take high level of risks to obtain potentially large profits, which is represented by large amount of maximum loss allowance. They make go decisions in bids more often than other contractors. These contractors' bids tend to be low, therefore they enjoy high success rates. However, their average profit per job is relatively low. They obtain more jobs, but there are risks of losses from the jobs obtained.

Most risk-averse contractors are more selective in their go/no-go decisions. They desire to avoid the risks of losses, which leads to frequent no-go decisions than other types of contractors. They allow small amount of possible losses, which is represented by small amount of maximum loss allowance. They decline to bid when their perceived risk is greater than their own maximum loss allowances, which are small. These contractors have low success rates since their bids tend to be high. Therefore, they enjoy high profits per job if they win jobs, however they cannot obtain many jobs, which leads to overhead burden with few jobs.

Therefore, most risk-tolerant and most risk-averse contractors have critical shortcomings even though they also have their own advantages, high success rate and high average profit per job, respectively. The shortcomings are large losses to most risk-tolerant and moderately risk-tolerant contractors and overhead burden to most risk-averse contractors. These shortcomings can threaten individual contractor's business operation and financial condition. A large loss from a single job can lead a contractor to

bankruptcy, a state from which the contractor cannot return. Overhead burden due to few jobs with a high capacity deteriorates a contractor's business operation.

Moderately risk-averse contractors can take trade-offs between the extreme advantages and disadvantages. By being moderately risk-averse, contractors can reduce risks of large losses or overhead burden, which leads the contractors to longer survival and accumulation of profits. Moderate profits from jobs and moderate success rate are better off than obtaining only one of the extreme advantages at the expense of the extreme disadvantages. Based on these strengths of moderate risk-aversion, these contractors can survive longer and make more profits to build financial resources.

Heterogeneity in size among contractors is a result of competition among themselves in the market. Moderately risk-averse contractors are favored in growth based on their continuous accumulations of moderate profits. Building on financial resources, these contractors can grow and continue their successful business with an increased capacity. To grow, a firm should survive and maintain its successful business over long periods, not transiently.

By diversification, a contractor (a firm) extends its competition activities to other markets by opening new establishments. A firm and its establishments have an organizational standard about what level of risks can be accepted or not within the firm, which is organizational risk attitude. So, establishments under a parent firm behave similarly in their risk-taking. The study results found outperformance of moderate risk-aversion also at the establishment level. Thus, moderately risk-averse contractors are

successful in their market diversification. Also, it was found that market diversification with moderate risk-aversion enables contractors to grow more.

In the real market, different market segments may have different characteristics such as different levels of risk and competition. Then, the appropriate level of risk attitude for survival and growth might differ. However, the evolutionary model shows that the aggregate industry patterns similar to the actual data can be developed without differentiation of the market segments while demonstrating the invariant strength of moderate risk-aversion in competitive success. It indicates that the effects of contractors' risk attitude are so critical in the construction business that the moderate risk-aversion is commonly favored in different market segments.

Successful business operation by each establishment in different market segments leads to overall better performance of their parent firm. Moderately risk-averse contractors are more diversified and their moderately risk-averse establishments are also more successful than other firms' establishments. Moderately risk-averse and diversified firms have their establishments as buffers against market risks and firm failure. They have longer longevity.

As a result, as also highlighted based on the sensitivity analyses, moderate risk-aversion is essential to contractors' survival, growth, and diversification. Also, it should be noted that, based on the study results, the moderate risk-aversion outperforms risk-neutrality that is the fundamental basis of the evaluations using expected monetary value theory. Then, a contractor needs to aware of the results of the current study when it has

to make a decision under uncertainty relying on such an evaluation using expected monetary value theory.

8.2 Recommendations for Construction Contractors

The study uncovers the critical effects of contractors' risk attitude and provides insights for management that have not been available using conventional approaches. Based on the current study results, to succeed, construction contractors need to be moderately risk-averse in their business decisions, in particular for their bidding strategies. By being moderately risk-averse, a contractor is able to maintain a stable business operation while avoiding critical risks. With some luck, contractors can be successful by taking a risk-seeking strategy or a highly risk-averse strategy for a short-term. However, the luck does not last long enough to guarantee the firm's long-term survival and success.

Some contractors succeed during several years and then go out of business. In the ENR U.S. Top 400 Contractors, there have been cases that some contractors were ranked within the top 400 and then disappeared from the list after just a couple of years. Some of them cannot be found again on the list thereafter. Such firms may have failed and disappeared or, more likely, have been bought up by their competitors, which is a form of business failure. A firm's success requires a stable business operation and stable profit streams over long periods. Being moderately risk-averse is a way for contractors to enhance their chances to have such conditions and performances.

The study results are all statistical; they represent statistical association rather than causes and effects. Thus, for example, moderate risk-aversion is associated with higher survival rates, higher profitability, greater diversification, longer longevity, etc. In the model, firms cannot change their risk aversion; they expand, live, diversify, and die with the same risk attitude that they were born with. However, some firms with certain risk attitudes live longer, grow more, diversify more, and are more profitable than others. Therefore, it seems reasonable that if firms could modify their risk attitudes they could transfer from a less favorable class to a more favorable class.

It is not easy to measure organizational risk attitude since an individual contractor's own position in risk attitude is relative within the domain of competition. For individual contractors, it is recommended to take an adaptive approach to identifying and modifying their own risk attitudes. If a contractor is satisfied with its current situation in terms of profitability and market share, the contractor does not need to change its behavior in risk-taking. If a contractor recognizes that it has satisfactory market share, but profitability per job is low, which are phenomena found for most risk-tolerant or moderately risk-tolerant firms, the contractor needs to try to become more risk-averse from its current attitude. In contrast, if a contractor feels that profitability per job is satisfactory but desires to grow, which are phenomena found for most risk-averse firms, the firm needs to try to become less risk-averse from its current attitude. This adaptive approach should be taken on the basis of an objective evaluation of a contractor's own performance. Over time, by making incremental adjustments, a firm may be able to modify its culture regarding risks.

Self-awareness (understanding current risk attitude) is the first step to managing risk attitude (Hillson and Murray-Webster, 2005). Identifying subconscious part of an organization is not easy. However, some approaches such as the following need to be taken by a contractor to identify and change its own risk attitude.

Evaluation of a contractor's own risk attitude can be performed by conducting post-project studies. The studies allow a contractor to compare and analyze its own measure of risk for a project at the time of bidding (*ex-ante* measure) against the realized results at the completion of the project (*ex-post* measure). It requires a contractor to document relevant processes of risk evaluation, which helps the contractor learn about its own risk perception and evaluation. In a study, cost elements in a bid amount (direct costs, overhead (project/general), contingency, profits or markup, etc.) can be compared with the actual costs. The contractor needs to figure out: what risks were underestimated; what risks were overestimated; and why. Based on these, the contractor needs to find which elements need to or should have been adjusted with respect to the realized results compared to the perceived risks; and which elements can be adjusted in terms of risk management (to be more or less risk-averse).

The current study makes another recommendation to construction contractors: to diversify. Diversification is a corporate strategy for growth. And, diversified contractors live longer since they have more establishments in multiple sectors, which are buffers against market risks. In general, less diversified or specialized contractors fail sooner than more diversified contractors since they are directly exposed to market risks.

However, the current study found that in order to diversify and also to be successful in the diversification, a contractor needs to be moderately risk-averse. Let consider most risk-tolerant or most risk-averse contractors, these contractors can also expand in size and diversify into other markets when they earn profits. What is waiting after an expansion or a diversification? An expansion or a diversification means an increase in capacity, which leads to needs to obtain more jobs and profits to pay the increased overhead with the increased capacity. If fewer jobs, a contractor's use of its capacity becomes inefficient. If large losses, a contractor's financial condition goes worse than before it expanded or diversified. So, a contractor could suffer a large loss or go out of business after an unsuccessful expansion or diversification. To be successful in diversification, a contractor needs to be moderately risk-averse. It enhances the contractor's survival and continuous earnings that are the basis of success in growth and diversification.

8.3 Contributions

8.3.1 Investigation on Missing Linkage between Risk-taking and Competition

A new insight from the current study is that risk attitude is not a single decision factor for an individual firm's bid decision, but it should be considered as the critical and universal element of competition from a broad perspective. Since the main objective of previous competitive bidding studies was finding the optimum markup or bid amount for

an individual contractor to win a job, these studies took individual perspective for individual contractors to win a job. And, risk attitude has been considered as a decision factor that an individual contractor considers for itself. But, competitors in a competition may have their own risk attitude and therefore behave differently in their risk-taking under competition, which affects the competition among themselves and further the performance of each competitor. The current study investigated critical relationship between risk-taking behaviors and competition by allowing heterogeneity in risk attitude among contractors in competition.

8.3.2 New Method to Represent Construction Contractors' Risk Attitude and Behaviors

The study proposed a new and simple method to represent risk attitude for construction contractors. The method is advantageous over the conventional method using expected utility. The concepts of maximum loss allowance and VaR are simple and easy to understand. Also, the method represents the way real business managers perceive their risks and uses a simple and quantitative measure, i.e., dollars. The proposed new method should be easy for practitioners to understand and apply for their practical business. The new method was validated based on the comparison with the conventional method.

8.3.3 Empirical Findings for the Construction Industry

The study presents new empirical findings in the construction industry: the size distribution of contractors and their diversification patterns. In construction, these

patterns have not received enough attention by researchers and practitioners even though these are realized effects at the aggregate level by competition in this highly competitive industry. The analyses using the U.S. construction industry data found the presence of the power law in the size distribution of contractors and the stable pattern of market diversification. In addition, the data analyses found there are differences in slope of the size distributions of contractors between different market sectors, which brings opportunity of further studies.

8.3.4 Evolutionary Approach for Comprehensive and Multiple Perspectives

The applied evolutionary approach to the current investigation allowed comprehensive and multiple perspectives. The developed evolutionary model simulates competition among contractors that have individual differences in risk-taking behavior depending on their own risk attitude. The evolutionary model tracks effects of different risk attitudes on the competing individuals' performances and the aggregate patterns that evolve at the population level. Analyses were performed at multiple levels, from individuals to the aggregate. The study results confirm that the empirical findings of the industry patterns in Chapter IV are results of the competition among contractors.

8.3.5 Long-term Analysis on Success of Firms

Success of firms has been analyzed within the domain of competition for the long-term considering individual contractors' life-cycle: birth, survival, expansion, diversification, contraction, and death. The current study showed that the industry

overall capacity changes occur by individual contractors' employment changes and these changes are also resultants of competition in the market place. This comprehensive market perspective extended the analysis of contractors' success from winning a job in competitive bidding.

8.4 Discussion

There would be many other factors that may affect competition among contractors and the contractors' competitive success in the real market. However, the developed simulation model produces aggregate patterns that are similar to the actual industry patterns without presenting the other factors. Other competitive factors would include expertise in a certain area, better management techniques, learning from more experience, good relationships with owners, relationships with good subcontractors and suppliers, better cost estimation capability, and so forth. Of course, no data are available on all these factors. These competitive factors exemplified above should be developed within a firm throughout continuous and successful business, which requires the firm to survive and to grow. The current study confirms that moderate risk-aversion is critical to firm survival and growth.

In any model, one tries to keep the number of independent variables to a workable number, by the principle of parsimony (Occam's razor). The model that best predict the dependent variable with the fewest independent variables is the best model. The evolutionary model developed in the current study uses as few assumptions as

possible and the used assumptions are simple and plausible. Although any model is a simplification, the current study results indicate that contactors can improve their performance through growth and diversification by changing their risk attitudes. If a firm can change its culture, then it can change its attitude toward risk and improve its performance.

In the real market, there are some contractors specialized in one market sector and they are successful. Especially, such cases are found in the U.S. highway construction market. How are these specialized firms successful? The highway construction sector has enjoyed a large number of projects from governmental agencies due to the increasing needs of infrastructure in the U.S. In addition, highway construction needs a high level of capital, which develops a relatively high entry barrier compared to other sectors. These facts would be the reasons for some highway contractors to survive and be successful without diversification. Further investigation is needed to understand their success.

8.5 Study Limits and Proposal of Future Studies

The approaches in the current study can be extended for the uses in other areas where competition are concerned allowing the long-term and multiple perspectives. The study needs to be extended to investigate other aspects of market competition and risk management, which include contractors' business failures, growth/diversification strategies, owners' risk management, interactions/competitions between owners and

contractors, and industry dynamics. More hidden linkages between risk management and competition in the construction business are waiting for further investigation.

Following are possible extensions.

For the last 14 years, the U.S. construction market has been in good shape. The market demand has been increasing steadily. However, it is natural to predict that there will be decreases in the market demand relatively compared to current level of industry capacity in some future times. The construction industry is subject to the general economic condition. Effects of changes in market condition need to be investigated with respect to contractors' risk management and diversification strategy.

To better understand market diversification, the current study needs to be extended to represent differences between market sectors. Different types of construction jobs have different characteristics in terms of difficulty, need of technology, size of job, need of large capital or equipment, different overhead rate, etc. Also, the levels of risk and competition could differ. The differences between market sectors and the effects of them needs to be investigated in association with the differences in the slop of size distributions of contractors between different market sectors found in Chapter IV using the actual industry data.

As to contractors' risk-taking and owners' risk-transfer, there are other contract methods used in the industry such as cost plus fee, unit price contract, negotiated price contract, CM at fee, CM at risk, etc. In the current study, competitive bidding, therefore lump sum contract, is represented as the major mechanism of competition in the construction market. In fact, many contractors still obtain the majority of their jobs

through competitive bidding, especially more in the public sector. Other contract methods and project delivery methods need to be studied within the domain of competition considering contractors' and owners' risk management.

REFERENCES

- Ahmad, I. (1990). "Decision-support system for modeling the bid/no bid decision problem," *Journal of Construction Engineering and Management*, ASCE, 116 (4), 595-607.
- Ahmad, I. and Minkarah, I. A. (1987). "Optimum mark-up for bidding: a preference-uncertainty trade off approach," *Civil Engineering Systems*, 4 (12), 170-174.
- Akinci, B. and Fischer, M. (1998). "Factors affecting contractors' risk of cost overburden," *Journal of Management in Engineering*, 14 (1), 67-77.
- Allan, D. (2005). "Evolution and natural selection," Lecture note of global change 1 – physical process, University of Michigan, Ann Arbor, MI.
<http://www.globalchange.umich.edu/globalchange1/>
- Altman, E. (1968). "Financial ratios, discriminant analysis and the prediction of corporate bankruptcy," *Journal of Finance*, 23 (4), 589-609.
- Altman, E. (1983). *Corporate financial distress*, John Wiley & Sons, New York, NY.
- Arditi, D., Koksas, A. and Kale, S. (2000). "Business failures in the construction industry," *Engineering, Construction, and Architectural Management*, 7 (2), 120-132.
- Barney, J. B. (1986). "Organizational culture: Can it be a source of sustained competitive advantage?" *Academy of Management Review*, 11 (3), 656-665.
- Benjamin, N. B. H. (1969). *Competitive bidding for building construction contracts*, Technical Report No. 106, Department of Civil Engineering, Stanford University, Palo Alto, CA.
- Benjamin N. B. H. (1972). "Competitive bidding: the probability of winning," *Journal of the Construction Division*, Proceedings of the ASCE, 98 (2), 313-330.
- Besanko, D., Dranove, D., Shanley, M., and Schaefer, S. (1996). *Economics of strategy*, John Wiley & Sons, New York, NY.
- Betts, M. and Ofori, G. (1992). "Strategic planning for competitive advantage in construction," *Construction Management and Economics*, 10 (6), 551-532.

- Boughton, P. D. (1987). "The competitive bidding process: beyond probability models," *Industrial Marketing Management*, 16 (2), 87-94.
- Bowman, E. H. (1980). "A risk-return paradox for strategic management," *Sloan Management Review*, 21 (3), 17-31.
- Broemser, G. M. (1968). *Competitive bidding in the construction industry*, Ph.D. Dissertation, Stanford University, Palo Alto, CA.
- Bromiley, P. (1991). "Testing a causal model of corporate risk-taking and performance," *Academy of Management Journal*, 34 (1), 37-59.
- Calori, R. & Sarnin, P. (1991). "Corporate culture and economic performance: a French study," *Organization Studies*, 12 (1), 49-74.
- Camerer, C. and Vepsalainen, A. (1988). "The economic efficiency of corporate culture," *Strategic Management Journal*, 9, Special Issue: Strategy Content Research, 115-126.
- Carbone, C. and Gittleman, J. L. (2002). "A common rule for the scaling of carnivore density," *Science*, 295 (5563), 2273-2274.
- Carr, Robert I. and Sandahl, J. W. (1978). "Bidding strategy using multiple regression," *Journal of the Construction Division, Proceedings of the ASCE*, 104 (1), 15-26.
- Chang, Y. and Thomas, H. (1989). "The impact of diversification strategy on risk-return performance," *Strategic Management Journal*, 10 (3), 271-284.
- Chatman, J. A. and Jehn, K. A. (1994). "Assessing the relationship between industry characteristics and organizational culture: how different can you be?" *Academy of Management Journal*, 37 (3), 522-553.
- Chao, L. and Liou, C. (2007). "Risk-minimizing approach to bid-cutting limit determination," *Construction Management and Economics*, 25 (8), 835-843.
- Chen, Y. K. (1991). *An analysis of decision strategy as applied to construction portfolios*, Ph.D. Dissertation, Stevens Institute of Technology, Hoboken, NJ.
- Choi, J. and Russell, J. S. (2005). "Long-term entropy and profitability change of United States public construction firms," *Journal of Management in Engineering*, 21 (1), 17-26.

- Christodoulou, S. E. (1998). *Optimum bid markup calculation in competitive bidding environments using fuzzy artificial neural networks*, Ph.D. Dissertation, Columbia University, New York, NY.
- Chua, D. K. H. and Li, D. (2000). "Key factors in bid reasoning model," *Journal of Construction Engineering and Management*, ASCE, 126 (5), 349-357.
- Construction Financial Management Association (1996) *Construction industry annual financial survey*, 8th edition, Kruse & Associates, P.C., Princeton, NJ.
- Construction Financial Management Association (1997) *Construction industry annual financial survey*, 8th edition, Kruse & Associates, P.C., Princeton, NJ.
- Construction Financial Management Association (1998) *Construction industry annual financial survey*, 8th edition, Kruse & Associates, P.C., Princeton, NJ.
- Construction Financial Management Association (2000) *Construction industry annual financial survey*, 8th edition, Kruse & Associates, P.C., Princeton, NJ.
- Construction Financial Management Association (2002) *Construction industry annual financial survey*, 8th edition, Kruse & Associates, P.C., Princeton, NJ.
- Curry, B. and George, K. D. (1981). "Industrial concentration: a survey," *Journal of Industrial Economics*, 31 (3), 203-255.
- Damuth, J. (1981). "Population density and body size in mammals," *Nature*, 290 (5808), 699-700.
- Dearden, J. A., Lilien, G. L., and Yoon, E. (1999). "Marketing and production capacity strategy for non-differentiated products: winning and losing at the capacity cycle game," *International Journal of Research in Marketing*, 16(1), 57-74.
- de Neufville, R., Hani, E. N., and Lesage, Y. (1977). "Bidding models: effects of bidders' risk-aversion," *Journal of the Construction Division, Proceedings of the ASCE*, 103 (1), 57-70.
- Dosi, G., Marsili, O., Orsenigo, L., and Salvatore, R. (1995). "Learning, market selection and the evolution of industrial structures," *Small Business Economics*, 7 (6), 411-436.
- Dozzi, S. P., AbouRizk, S. M., and Schroeder, S. L. (1996). "Utility-theory model for bid market decisions," *Journal of Construction Engineering and Management*, ASCE, 122 (2), 119-124.

- Drew, D. and Skitmore, M. (1997). "The effect of contract type and size on competitiveness in bidding," *Construction Management and Economics*, 15 (5), 469-489.
- Edmister, R.O. (1971). "Financial ratios and credit scoring for small business loans," *Journal of Commercial Bank Lending*, 7 (2), 1477-1493.
- Engineering News-Record (ENR) (1995). "The top 400 contractors," 234 (20), 46-61, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (1996). "The top 400 contractors," 236 (20), 48-65, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (1997). "The top 400 contractors," 238 (21), 64-81, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (1998). "The top 400 contractors," 240 (21), 65-80, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (1999). "The top 400 contractors," 242 (21), 79-96, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2000). "The top 400 contractors," 244 (20), 95-115, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2001). "The top 400 contractors," 246 (20), 73-89, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2002). "The top 400 contractors," 248 (19), 63-76, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2003). "The top 400 contractors," 250 (19), 85-101, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2004). "The top 400 contractors," 252 (20), 44-62, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2005). "The top 400 contractors," 254 (19), 34-48, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2006). "The top 400 contractors," 256 (20), 60-75, McGraw Hill Construction, New York, NY.

- Engineering News-Record (ENR) (2007). "The top 400 contractors," 258 (19), 58-73, McGraw Hill Construction, New York, NY.
- Engineering News-Record (ENR) (2008). "The top 400 contractors," 260 (17), 60-75, McGraw Hill Construction, New York, NY.
- Erwin, D. H. and Krakauer, D. C. (2004). "Insights into innovation," *Science*, 304, 1117-1119.
- Fayek, A. (1998). "Competitive bidding strategy model and software system for bid preparation," *Journal of Construction Engineering and Management*, ASCE, 124 (1), 1-10.
- Fiegenbaum, A. and Thomas, H. (1985). "An examination of the structural stability of Bowman's risk-return paradox," *Academy of Management Proceedings*, 44th Annual Meeting of the Academy of Management, San Diego, 7-11.
- Fiegenbaum, A. and Thomas, H. (1988). "Attitudes toward risk and the risk-return paradox: prospective theory explanations," *Academy of Management Journal*, 31 (1), 85-106.
- Fiol, C. M. and Lyles, M. A. (1985). "Organizational learning," *Academy of Management Review*, 19 (4), 803-813.
- Forgang, W. G. and Einolf, K. W. (2006). "Management economics: an accelerated approach," M.E. Sharpe, Armonk, NY.
- Friedman, L. (1956). "A competitive-bidding strategy," *Operations Research*, 4 (4), 104-112.
- Frimpong, Y., Oluwoye, J., and Crawford, L. (2003). "Causes of delay and cost overruns in construction groundwater projects in a developing countries: Ghana as a case study," *International Journal of Project Management*, 21 (5), 321-326.
- Fuerst, M. (1976). "Bidding models: truths and comments," *Journal of Construction Division*, ASCE, 102, 169-177.
- Gates, M. (1967). "Bidding strategies and probabilities," *Journal of Construction Division*, ASCE, 93, 75-103.
- Gibrat, R. (1931). *Les inégalités économiques; applications: aux inégalités des richesses, à la concentration des entreprises, aux populations des villes, aux statistiques des familles, etc., d'une loi nouvelle, la loi de l'effet proportionnel*, Librairie du Recueil Sirey, Paris.

- Gort, M. (1962). *Diversification and integration in American industry*, National Bureau of Economic Research, General Series 77, Princeton University Press, Princeton, NJ.
- Griffis, F. H. (1971). *A stochastic analysis of the competitive bidding problem for construction contractors*, Ph.D. Dissertation, Oklahoma State University, Stillwater, OK.
- Hall, G. (1994). "Factors distinguishing survivors from failures amongst small firms in the UK construction sector," *Journal of Management Studies* 31(5), 737-760.
- Han, S. H. Diekmann, J. E. Lee, Y. and Ock, J. H. (2004). "Multicriteria financial portfolio risk management for international projects," *Journal of Construction Engineering and Management*, ASCE, 130 (3), 346-356.
- Hannan, M. T. and Freeman, J. (1977). "The population ecology of organizations," *American Journal of Sociology*, 82 (5), 929-964.
- Hannan, M. T., Ranger-Moore, J., and Banaszak-Holl, J. (1990). "Competition and the evolution of organizational size distributions," 246-268, in Singh, J. V. (1990), *Organizational evolution: new directions*, SAGE Publication, Newbury Park, CA.
- Hegazy, T. and Moselhi, O. (1995). "Elements of cost estimation: a survey in Canada and the United States," *Cost Engineering*, 1995, 37 (5), 27-33.
- Heney, J. E. (1985). "Specialization as a strategy for growth", *Journal of Management in Engineering*, 1 (4), 181-187.
- Hillebrandt, P. M. and Cannon, J. (1989). "Diversification," in *The Management of construction firms: aspects of theory* (edited by Hillebrandt, P. M. and Cannon, J.), Macmillan, London, 31-42.
- Hillson, D. and Murray-Webster, R. (2005). *Understanding and managing risk attitude*, Gower Publishing Ltd., Burlington, VT.
- Ijiri, Y. and Simon, H. A. (1967). "A model of business firm growth," *Econometrica*, 35 (2), 348-355.
- Ilmakunnas, P. and Topi, J. (1999). "Microeconomic and macroeconomic influences on entry and exit of firms," *Review of Industrial Organization*, 15 (3), 283-301.
- Jacquemin, A. P. and Berry, C. H. (1979). "Entropy measure of diversification and corporate growth," *Journal of Industrial Economics*, 27 (4), 359-369.

- Jorion, P. (2001). *Value at risk: the new benchmark for managing financial risk*, 2nd edition, McGraw-Hill, New York, NY.
- Jovanovic, B. (1982). "Selection and the evolution of industry," *Econometrica*, 50 (3), 649-670.
- Junnonen, J. M. (1998). "Strategy formation in construction firms," *Engineering, Construction and Architectural Management*, 5 (2), 107-114.
- Kahneman, D. and Tversky, A. (1979). "Prospect theory: an analysis of decision under risk," *Econometrica*, 47 (2), 263-292.
- Kaming, P. F., Olomolaiye, P. O., Holt, G. D. and Harris, F. C. (1997). "Factors influencing construction time and cost overruns on high-rise projects in Indonesia," *Construction Management and Economics*, 15 (1), 83-94.
- Kangari, R. (1988). "Business failure in construction industry," *Journal of Construction Engineering and Management*, ASCE, 114 (2), 172-190.
- Keddy, P. A. (1989). *Competition – population and community biology*, Chapman and Hall, New York, NY.
- Kim, H. J. (2004). *Dynamic competition model for construction contractors*, M.S. Thesis, Zachry Department of Civil Engineering, Texas A&M University, College Station.
- Kim, H. J. and Reinschmidt, K. F. (2006). "A dynamic competition model for construction contractors," *Construction Management and Economics*, 24 (9), 955-965.
- Koksal, A. and Arditi, D. (2004). "Predicting construction company decline," *Journal of Construction Engineering and Management*, ASCE, 130 (6), 799-807.
- Kotter, J. P. and Heskett, J. L. (1992). *Corporate culture and performance*, The Free Press, New York, NY.
- Kwaśnicki, W. (1998). "Skewed distribution of firm sizes – an evolutionary perspective," *Structural Change and Economic Dynamics*, 9 (1), 135-158.
- Lee, Jin-Kyung (2008). "Cost overrun and cause in Korean social overhead capital projects: roads, rails, airports, and ports," *Journal of Urban Planning and Development*, 134 (2), 59-62.

- Levinthal, D. A. (1991). "Organizational adaptation and environmental selection - interrelated processes of change," *Organization Science*, 2 (1), 140-145.
- Lin, C. and Chen, Y. (2004). "Bid/no-bid decision-making – a fuzzy linguistic approach," *International Journal of Project Management*, 22 (7). 585-593.
- Lucas, R. E. (1978). "On the size of business firms," *The Bell Journal of Economics*, 9 (2), 508-523.
- Marquet, P. A. (2000). "Invariants, scaling laws, and ecological complexity," *Science*, 289 (5484), 1487-1488.
- Marquet, P. A. (2002). "Of predators, prey, and power laws," *Science*, 295 (5563), 2229-2230.
- Marquet, P. A., Quinones, R.A., Abades, S., Labra F., Tognelli, M., Arim, M., and Rivadeneira, M. (2005). "Scaling and power-laws in ecological systems," *Journal of Experimental Biology*, 208, 1749-1769.
- Marzouk, M. and Moselhi, O. (2003). "A decision support tool for construction bidding," *Construction Innovation*, 3 (2), 111-124.
- Mayo, R. E. (1992). *Improved optimum bid markup estimation though workload related bid distribution functions*, Ph. D. Dissertation, Stevens Institute of Technology, Hoboken, NJ.
- Metcalfe, S. and Foster, J. (2004). *Evolution and economic complexity*, Edward Elgar Publishing, Northampton, MA.
- Mochtar, K. and Arditi, D. (2001). "Pricing strategy in the US construction industry," *Construction Management and Economics*, 19 (4), 405-415.
- Morin, L. T. and Clough H. R. (1969). "OPBID: Competitive bidding strategy model," *Journal of Construction Division*, ASCE, 95, 85-106.
- Molles, M. C. (2005). *Ecology: concepts and applications*, 3rd edition, McGraw-Hill, Boston, MA.
- Nelson, R. R. and Winter, S. G. (1977). "Simulation of Schumpeterian competition," *The American Economic Review*, 67 (1), 271-176.
- Nelson, R. R. and Winer, S. G. (1982). "An evolutionary model of economic growth," in *An evolutionary theory of economic change*, The Belknap Press of Harvard University Press, Cambridge, MA.

- Odeck, J. (2004). "Cost overruns in road construction – what are their sizes and determinants?" *Transport Policy*, 11 (1), 43-53.
- Palepu, K. (1985). "Diversification strategy, profit, performance and the entropy measure," *Strategic Management Journal*, 6 (3), 239-255.
- Pandya, A. M. and Rao, N. V. (1998). "Diversification and firm performance: an empirical evaluation," *Journal of Financial and Strategic Decisions*, 11 (2), 67-81.
- Pennings, J. M. E. and Smidts, A. (2000). "Assessing the construct validity of risk attitude," *Management Science*, 46 (10), 1337-1348.
- Pennings, J. M. E. and Smidts, A. (2003). "The shape of utility functions and organizational behavior," *Management Science*, 49 (9), 1251-1263.
- Peters, R. H. and Wassenberg, K. (1983). "The effect of body size on animal abundance," *Oecologia* (Berlin), 60 (1), 89-96.
- Power, M. (2002). "Fatal flaws: forward," *Builder*, 25(8), 101-103.
- Pratt, J. W. (1964). "Risk-aversion in the small and in the large," *Econometrica*, 32 (1/2), 122-136.
- Pries, F. and Janszen, F. (1995). "Innovation in the construction industry: the dominant role of the environment," *Construction Management and Economics*, 13 (1). 43-51.
- Ramsay W. (1989). "Business objectives and strategy," in *The management of construction firms: aspects of theory* (edited by Hillebrandt, P. M. and Cannon, J.), Macmillan, London, 9-29.
- Rawlinson, S and Raftery, J. (1997). "Price stability and the business cycle: UK construction bidding patterns 1970-91," *Construction Management and Economics*, 15(1), 5-18.
- Rice, H. and Heimbach, A. (2007). "Why contractors fail: a causal analysis of large contractor bankruptcies," *FMI Quarterly*, 2, 52-74.
- Rothkopf, M. H. and Harstad, R. M. (1994). "Modeling competitive bidding: a critical easy," *Management Science*, 40 (3), 364-384.
- Rubinstein, M. (2002). "Markowitz's portfolio selection: a fifty-year retrospective," *Journal of Finance*, 57(3), 1041-1045.

- Runeson, G. and Skitmore, M. (1999). "Tendering theory revisited," *Construction Management and Economics*, 17 (3), 285-296.
- Schein, E. H. (2004). *Organizational Culture and Leadership*, Jossey-Bass, Wiley, 3rd edition, San Francisco, CA.
- Schmid, P. E., Tokeshi, M., and Schmid-Araya, J. M. (2000). "Relation between population density and body size in stream communities," *Science*, 289 (5484), 1557-1560.
- Schwartz, H. and Davis, S M. (1981). "Matching corporate culture and business strategy," *Organizational Dynamics*, 10 (1), 30-48.
- Schumpeter, J.A. (1912/1934). *Theorie der wirtschaftlichen Entwicklung*, Leipzig: Duncker & Humblot. English translation published in 1934 as *The Theory of Economic Development*, Harvard University Press, Cambridge, MA.
- Scott, W. R. (1987). *Organizations: Rational, Natural, and Open Systems*, 2nd edition, Prentice-Hall, Englewood Cliffs, NJ.
- Seydel J. (1994). "Simulation model for competitive bidding in construction," *Proceedings of the 1994 Winter Simulation Conference*, 1439-1442.
- Shannon, C.E. (1948). "A mathematical theory of communication," *Bell System Technical Journal*, 27, 379-423 and 623-656.
- Shash, A. A. (1993). "Factors considered in tendering decisions by top UK contractors," *Construction Management and Economics*, 11 (2), 111-118.
- Shash, A. A. (1995). "Competitive bidding system," *Cost Engineering*, 37 (2), 19-20.
- Simon, H. A. and Bonini, C. P. (1958). "The size distribution of business firms," *The American Economic Review*, 48 (4), 607-617.
- Singh, J. V. (1990). *Organizational evolution: new directions*, SAGE Publication, Newbury Park, CA.
- Sørensen, J. B. (2002). "The strength of corporate culture and the reliability of firm performance," *Administrative Science Quarterly*, 47 (1), 70-91.
- Sounderpandian, J. (2007). "Evolutionary analysis of risk attitudes in competitive bidding environments using simulation," in *Uncertainty and risk: mental, formal, and experimental representations*, (edited by Abdellaoui, M., Luce, R. D., Machina, M. J., and Munier, B.), Springer, Berlin, 275-290.

- Summers, G. J. (1997). *Industrial dynamic: an evolutionary model for an interactive simulation*, Ph.D. Dissertation, Northwestern University, Evanston, IL.
- Tasi, C. (1994). *Diversification strategies for construction companies in the U.S.*, M.S. Thesis, Massachusetts Institute of Technology, Cambridge, MA.
- Viner, J. (1932). "Cost curves and supply curves," *Journal of Economics*, 3 (1), 23-46.
- von Neumann, J. and Morgenstern, O. (1944). *Theory of games and economic behavior*, Princeton University Press, Princeton, NJ.
- Walls, M.R. and Dyer, J. (1996). "Risk propensity and firm performance: a study of the petroleum exploration industry," *Management Science*, 42 (7), 1004-1021.
- Weverbergh, M (2002) "Viewpoint (A comment on "Predicting the probability of winning sealed bid auctions: a comparison of models)," *Journal of the Operational Research Society*, 53(10), 1156-1158.
- White, C. R. and Seymour, R. S. (2005). "Allometric scaling of mammalian metabolism," *Journal of Experimental Biology*, 208 (9), 161-1619.
- Willenbrock, J. H. (1973). "Utility function determination for bidding models," *Journal of the Construction Division*, ASCE, 99 (1), 133-153.

APPENDIX I

CLASSIFICATION OF THE INDUSTRY BY ENR

The ENR data classify the construction industry into eight sectors as below (ENR, 2005):

- General building: commercial buildings, offices, stores, educational facilities, government buildings, hospitals, medical facilities, hotels, apartments, housing, etc.
- Manufacturing: auto assembly, electronic assembly, textile plants, etc.
- Power: thermal and hydroelectric power plants, waste-to-energy plants, transmission lines, substations, cogeneration plants, etc.
- Water supply and sewerage/solid waste
 - Water supply: dams, reservoirs, transmission pipelines, distribution mains, irrigation canals, desalination and potability treatment plants, pumping stations, etc.
 - Sewerage/solid waste: sanitary and storm sewers, treatment plants, pumping plants, incinerators, industrial waste facilities, etc.
- Industrial process and petroleum
 - Industrial process: pulp and paper mills, steel mills, nonferrous metal refineries, pharmaceutical plants, chemical plants, food and other processing plants, etc.

- Petroleum: refineries, petrochemical plants, offshore facilities, pipelines, etc.
- Transportation: airports, bridges, roads, canals, locks, dredging, marine facilities, piers, railroads, tunnels, etc.
- Hazardous waste: chemical and nuclear waste, asbestos and lead abatement, etc.
- Telecommunications: transmission lines and cabling, towers and antennae, data centers and web hotels, etc.

APPENDIX II

SIZE DISTRIBUTION OF THE ENR U.S. TOP 400 CONTRACTORS

Before the Normalization

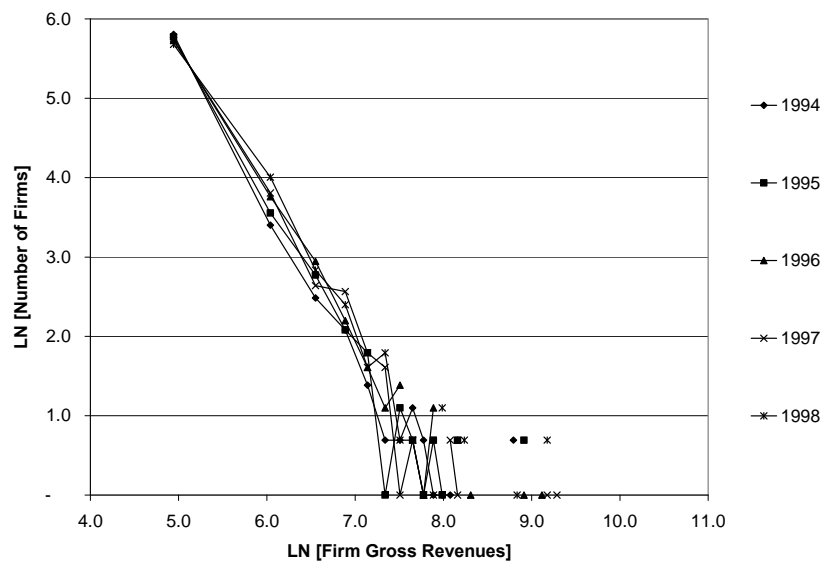


Figure II - 1. Size Distributions, before Normalization (1994 ~ 1998)

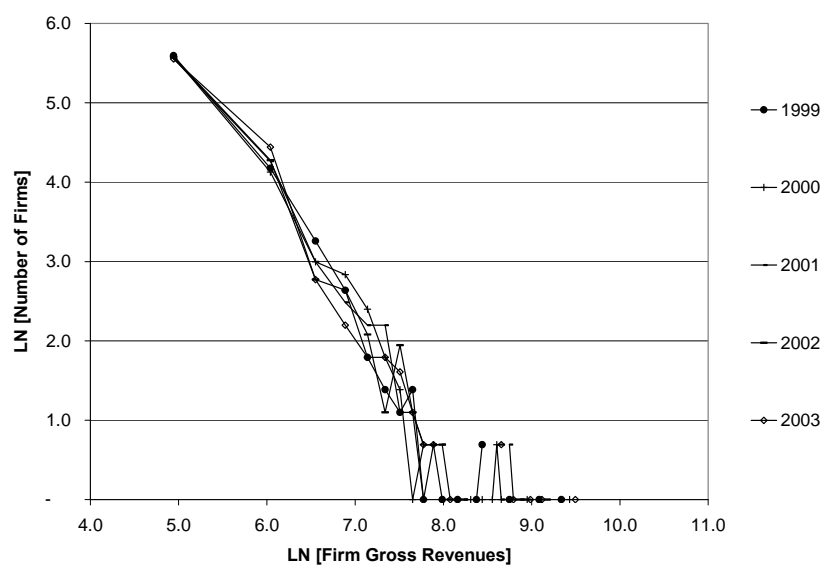


Figure II - 2. Size Distributions, before Normalization (1999 ~ 2003)

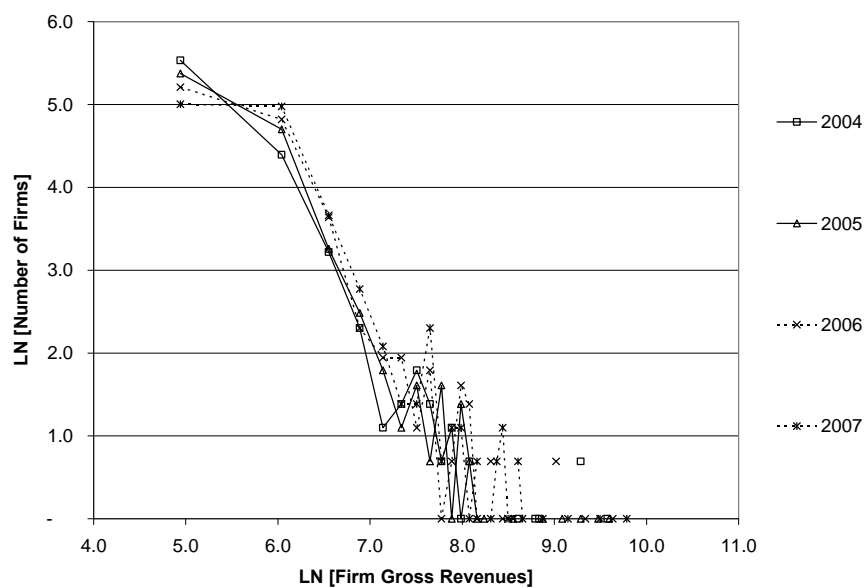


Figure II - 3. Size Distributions, before Normalization (2004 ~ 2007)

After the Normalization

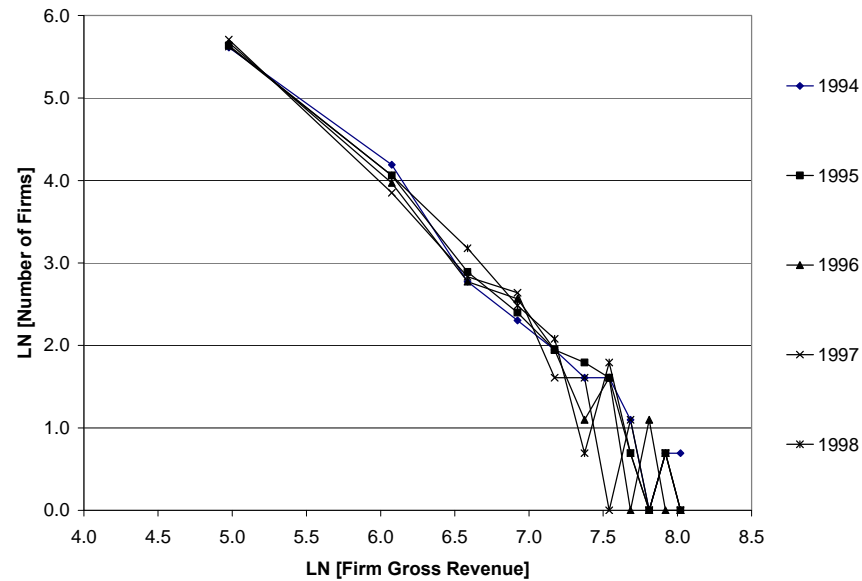


Figure II - 4. Size Distributions, Normalized (1994 ~ 1998)

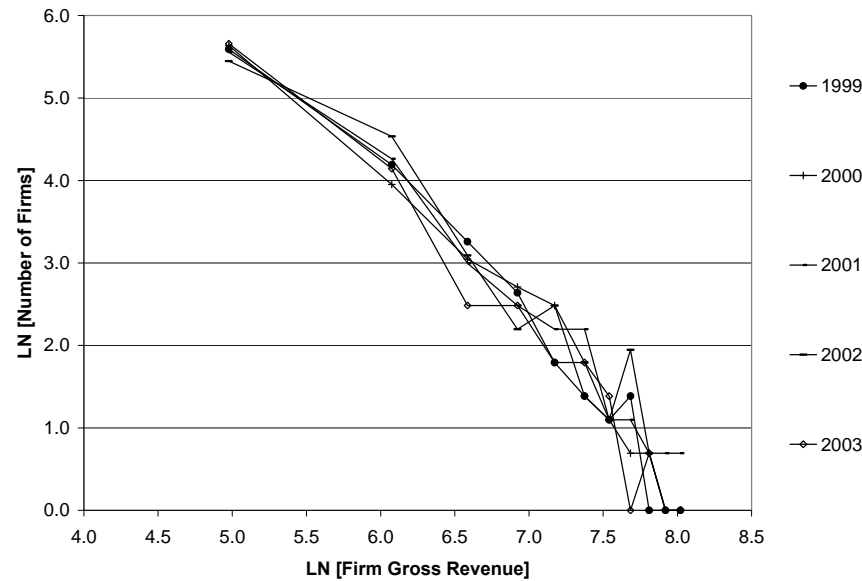


Figure II - 5. Size Distributions, Normalized (1999 ~ 2003)

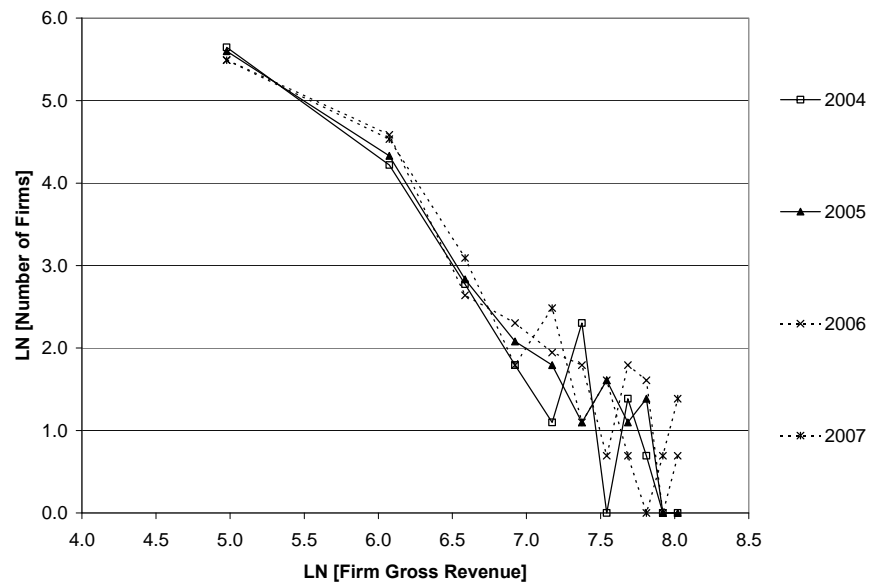


Figure II - 6. Size Distributions, Normalized (2004 ~ 2007)

Domestic Contractors

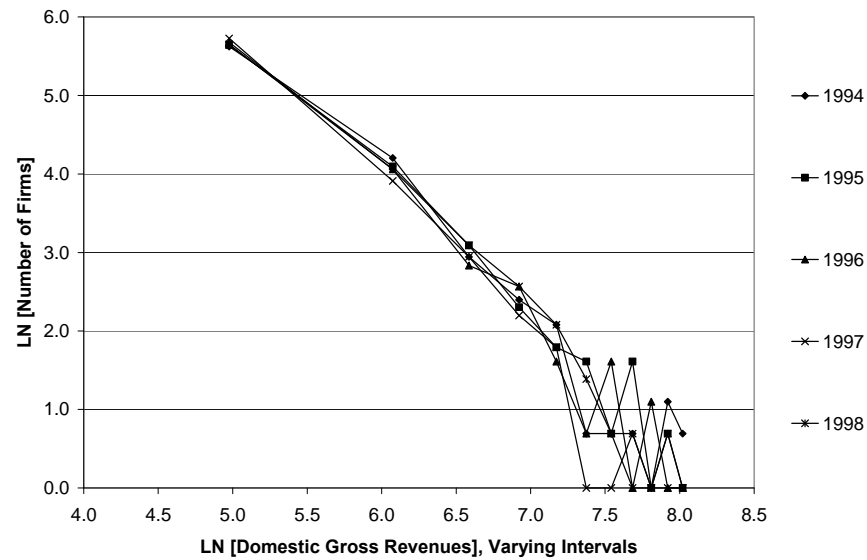


Figure II - 7. Size Distributions, Domestic Firms (1994 ~ 1998)

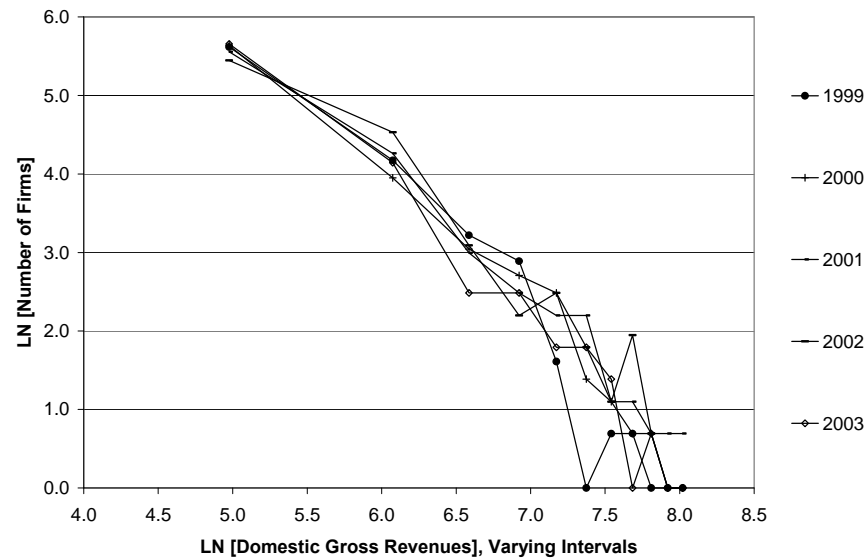


Figure II - 8. Size Distributions, Domestic Firms (1999 ~ 2003)

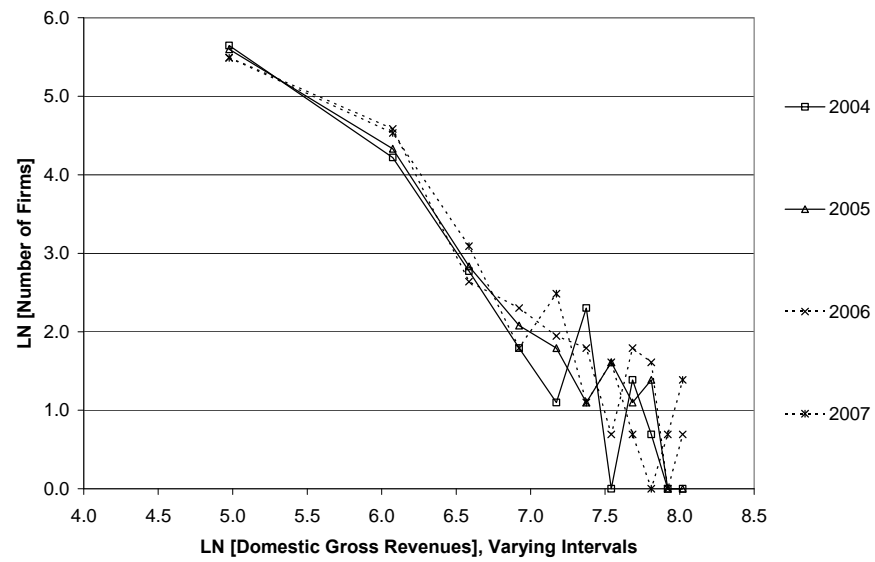


Figure II - 9. Size Distributions, Domestic Firms (2004~2007)

APPENDIX III

DIVERSIFICATION PATTERN OF THE ENR U.S. TOP 400

CONTRACTORS

All 400 Firms

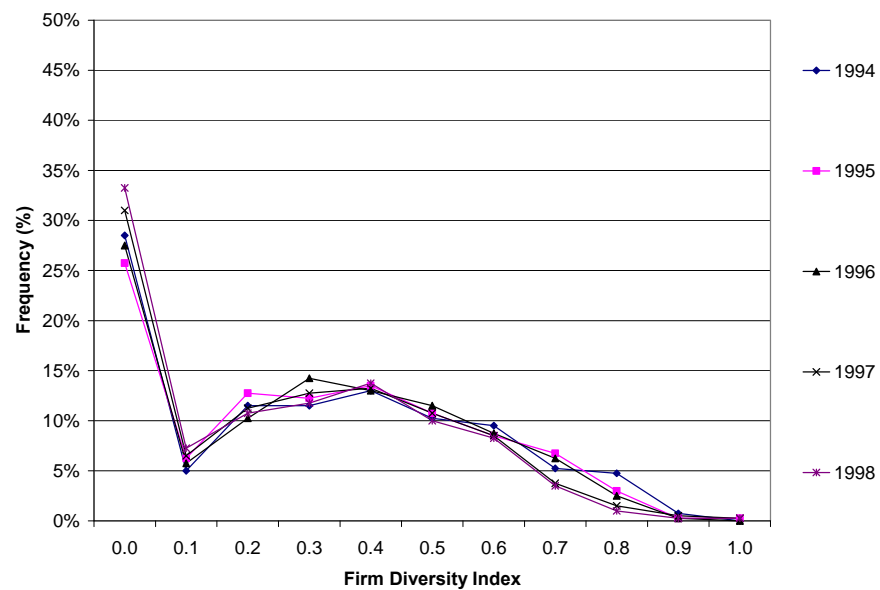


Figure III - 1. Diversification Pattern, All 400 Firms (1994~1998)

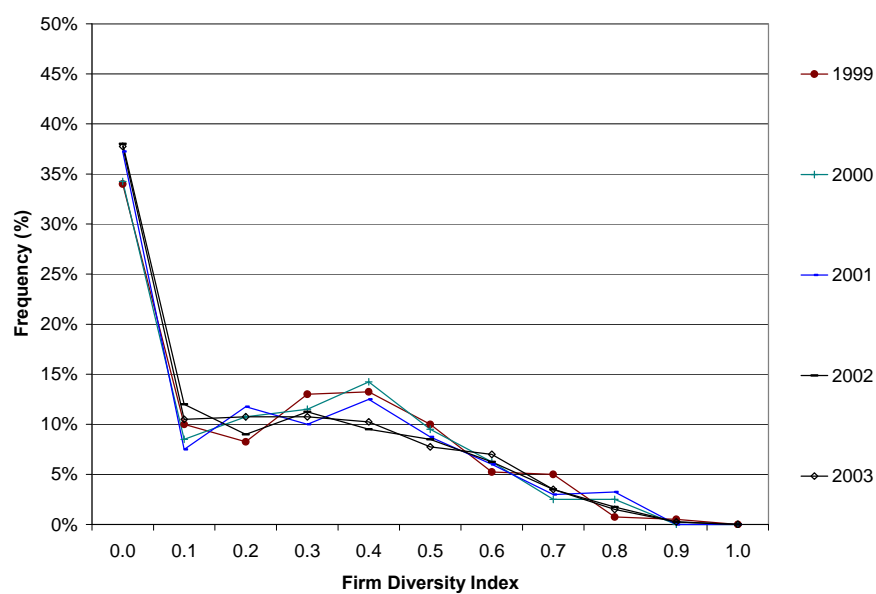


Figure III - 2. Diversification Pattern, All 400 Firms (1999~2003)

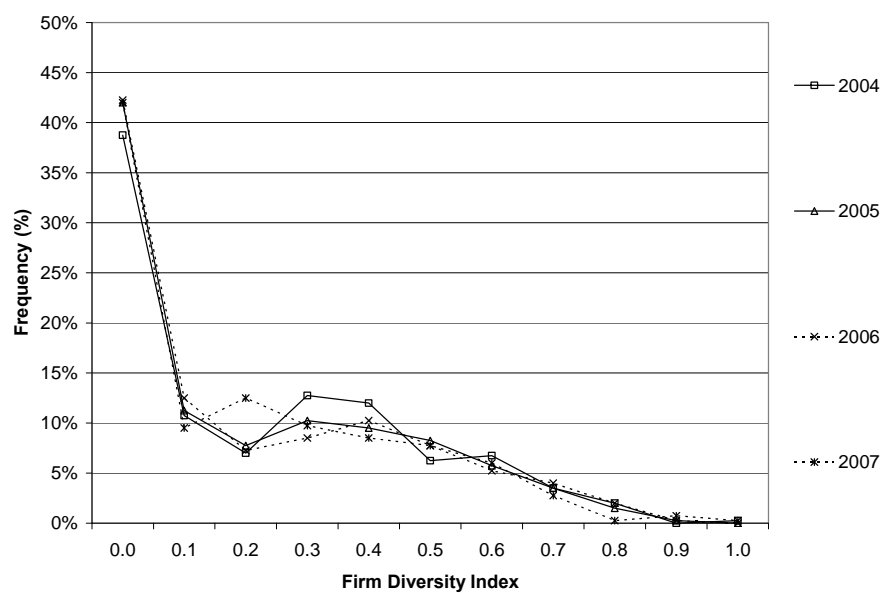


Figure III - 3. Diversification Pattern, All 400 Firms (2004~2007)

Domestic Firms

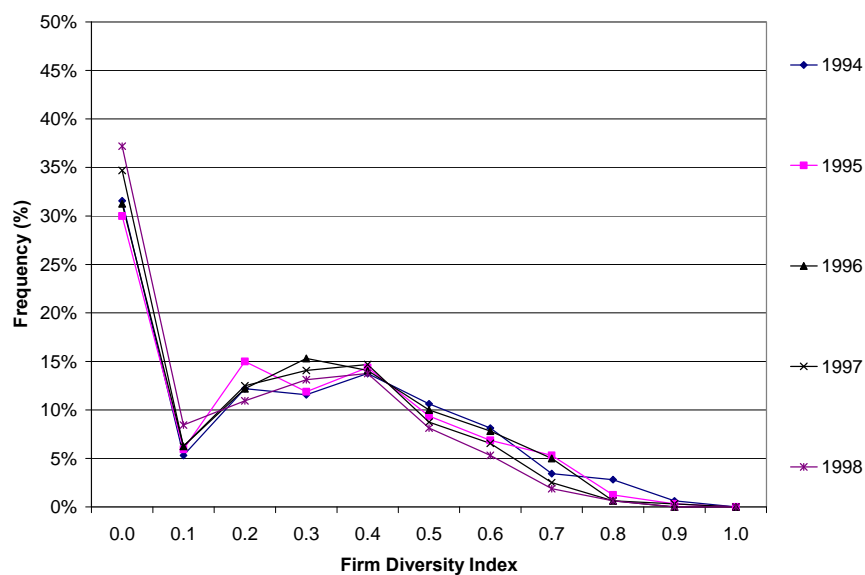


Figure III - 4. Diversification Pattern, Domestic Firms (1994~1998)

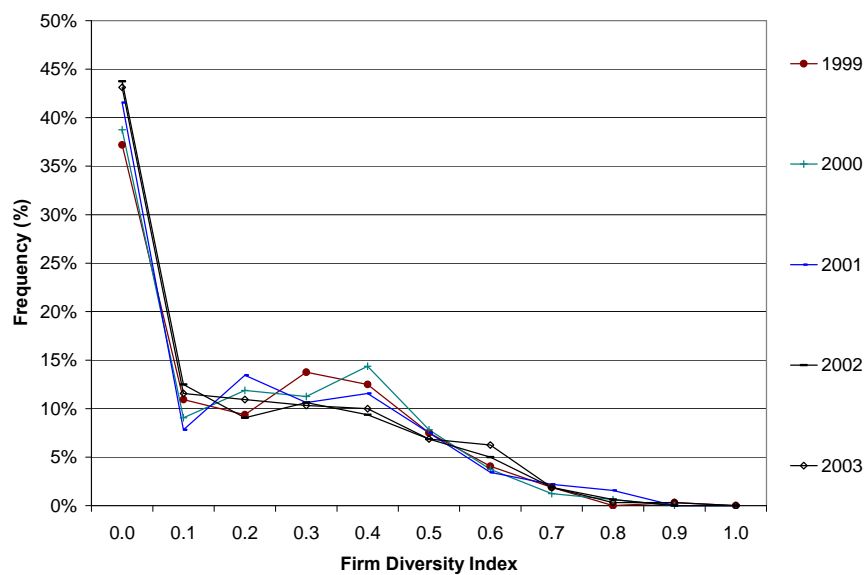


Figure III - 5. Diversification Pattern, Domestic Firms (1999~2003)

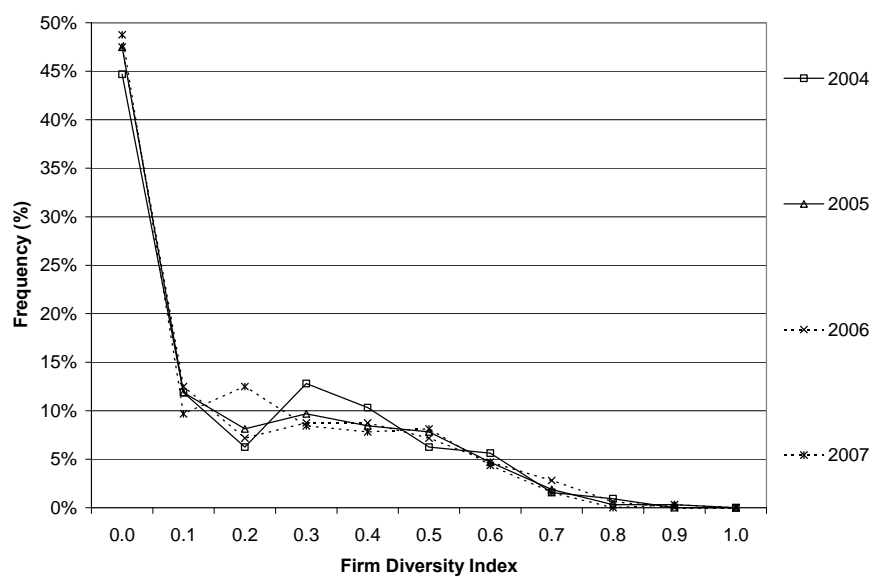
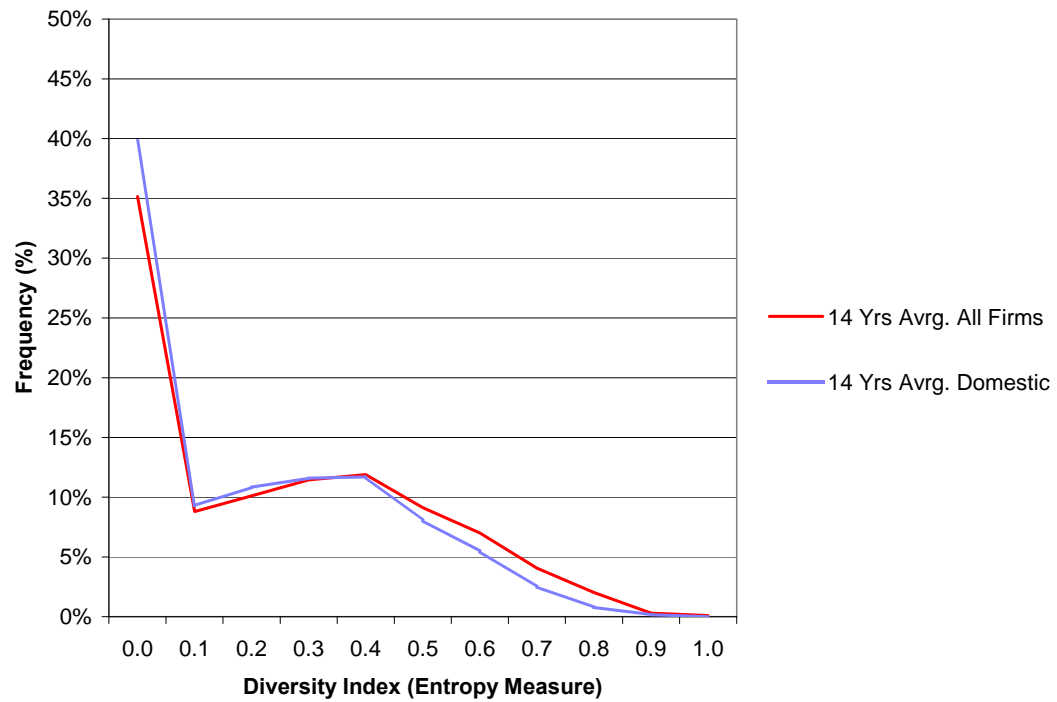


Figure III - 6. Diversification Pattern, Domestic Firms (2004~2007)

All 400 Firms vs. Domestic Firms**Figure III - 7. Comparison of Diversification Patterns (400 Firms vs. Domestic)**

VITA

Name: Hyung Jin Kim
Email Address: kudos@neo.tamu.edu, kudos2008@hotmail.com
Postal Address: Civil Engineering Department
c/o Dr. Kenneth Reinschmidt
Texas A&M University
College Station, TX 77843-3136
Education: B.S., Architectural Engineering, Konkuk University, 1997
M.S., Civil Engineering, Texas A&M University, 2004
Ph.D., Civil Engineering, Texas A&M University, 2009